MECHANICAL DRAWING

BY

JOHN E. JAGGER, M. Sc.

AN ELEMENTARY TEXT-BOOK

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PREFACE.

THE object of this book is to provide notes, observations, and examples, by the careful perusal of which it is hoped that a student may be able to acquire the ability—

1. To read a drawing with rapidity and accuracy.
2. To make a simple drawing so that any ordinary workman can understand what is required without difficulty, loss of time, or tendency to make a mistake.
3. To make use of the experience obtained by studying the examples in any future mechanical construction he may undertake.

Believing that a youth cannot understand the use of a mechanical drawing unless he has some idea of the object and use of the detail, together with the methods of manufacture, examples are incorporated to bring out these points.

The book is primarily intended for those students engaged in engineering work who do not have the opportunity to pass through the drawing office, to enable them to take greater interest in the work passing through their hands, by making them familiar with drawing office processes and methods.

When used as a text-book, and supplemented by the experience of the teacher in the ordinary way, it will most likely be useful to those students who have not yet commenced their practical career, but who wish to obtain some knowledge of mechanical drawing. For those students actually engaged in drawing office work, many points worthy of attention are incorporated.

The student in engineering must remember that it is as important for him to be able to read a simple drawing at sight as it is for every man to possess the ability to read his newspaper at sight, and that the ability to do this can only be obtained as the result of his own industrious labour. The young draughtsman is advised to become proficient in his profession by giving careful attention to technical work in his early years.

An attempt has been made to so grade the book that a student commencing at the beginning will finally finish up with interest in the subject and its allied sciences, and will also have obtained a good foundation on which he can build up further ability.

Many valuable hints may be given, and attention called to points worthy of improvement, by fellow-teachers actually engaged in using such a text-book as this; and all such suggestions will be gratefully received and acknowledged.

Finally, this work is produced from notes and observations made during many years of practice and teaching, and is an attempt to present the subject of Machine Construction and Drawing to the student in a rational manner.

JOHN E. JAGGER.

MANCHESTER, 1909.

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LIST OF ILLUSTRATIONS.

MECHANICAL DRAWING.

§ 1.—GENERAL IDEAS.

Mechanical Drawing. — Mechanical drawing is the language used in engineering practice to convey ideas and instructions from the designer and draughting room to the several departments of the workshop responsible for the economical production of the ultimate product. It is thus easily seen that, the more systematic the drawing in arrangement and detail, the more readily will it be understood by the various workmen. For this reason a new-comer in a drawing office is usually supplied with a copy headed "Rules, Data, and Standard Information," which embodies the standard style of the shop or firm, and to which, in his future work, he is expected to give particular attention.

Working Instructions.—To obtain uniformity in the type of drawing produced, it must be made on definite lines, for we must remember that the drawing office is a part of a concern which can have great influence upon the cost of production. The drawings turned out should be models of perfection in the way of systematic arrangement of details, numbering, lettering, accuracy, and completeness, and this should be achieved without any unnecessary expenditure of labour. To obtain drawings containing satisfactory information, orders, and instructions, before they are distributed to the shops, requires the same care, supervision, and inspection as does the actual production of the article itself.

To comply with the above requirements, a drawing when finished must satisfy some such set of conditions as the following:—

1. It must be one of the recognised standard sizes.
2. It should contain in good block letters—
   (1) In the bottom left-hand corner, the index number and the scale to which it is drawn; and
   (2) In the bottom right-hand corner, the title, consisting of the general heading to which it relates, the detail heading, a stamp giving surname of draughtsman, tracer, and checker, and the date of completion.
   (3) Commencing in the top right-hand corner, and forming a margin down the right-hand side of the drawing, there should be noted—
      (*a*) The index number;
      (*b*) List of drawings to which reference is required; and
      (*c*) Index of material, pattern number, number off, etc., for detail shown, and space for remarks relating to any alterations made.

3. On the general arrangement each detail must have a distinctive reference number, which must be the card number or detail drawing number of the detail.
4. General arrangements, complicated or large details must be on full- or half-size drawings. Otherwise details should be on a full- or half-size drawing divided up into standard cards.
5. Each card must contain one detail only, and must contain information as per section 2, having, in addition, the card number noted immediately over the index number.
6. The general lay-out of the drawing must follow the general office practice for similar classes of machinery and detail.
7. Centre lines, dimension lines, figures, and lettering must be of the standard type and pattern. The drawing must be clear and neat. There is no need to waste time on ornamentation.

   In figuring, use inches up to 2 feet, and feet and inches above. Diameters should always be stated in inches.

   Do not use odd dimensions unless absolutely essential. Main centres should always be in even figures, *i.e.* 6 feet 6 inches in preference to 6 feet $5\frac{13}{16}$ inches.

   The drawing must contain all necessary dimensions. It is not the work of the shops to figure out any measurements required.
8. All parts requiring machining are to be indicated on drawing by covered over with red, the method of machining, by planing, grinding, milling, profiling, etc., being left to the shops. All cored holes should be plainly marked.
9. All views must be projected clockwise, that is, from left to right.
10. *Before proceeding to make a drawing, read well the instructions, and know what you are going to do.*

Size of Drawings.—The drawing (or its reproductions) becomes a most valuable asset, owing not only to the cost of its production, but to the fact that it gives all information as to what was supplied for a particular order, so that it is important to keep a careful record of it. For this purpose its over-all size must lend itself to some system of filing or storing, and to help in this standard sizes are adopted. The actual dimensions vary in different works, but the following is a representative set of standard sizes which have been found useful in actual practice :—

A standard drawing must be . .	4 feet 0 inches × 2 feet 6 inches finished.
A standard half drawing must be .	2 „ 0 „ × 2 „ 6 „ „
A standard sketch must be . .	8 „ × 10 „ „

Whilst for manufacturing on a card system the card must be a subdivision of the standard drawing, such as 8 inches by 10 inches or 8 inches by 5 inches. For evening-class work the most convenient sizes are Imperial (2 feet 6 inches × 22 inches) and Half Imperial (15 inches × 22 inches).

Paper.—The class of paper used in various offices differs widely, as it is not usual for the actual drawing itself to be finished off and kept as the record. The tendency is towards using paper of a cheap quality for this purpose. Common practice is, however, for the designer to scheme out his machine on good cartridge paper. Details are then made, and a final arrangement set out

on "bank-note" paper, which is cheap, has a good surface, resisting the natural tendency to accumulate dirt, is obtained in rolls, cut off as required, and has the advantage that, for urgent jobs, photo prints can be taken from the drawings direct, without waiting for them to be traced.

Draughtsmanship.—To carry out the work of a draughtsman, and produce drawings in a commercial and manufacturing manner, certain apparatus is necessary. The following list and fig. 1 are given with the idea of showing the student in a general way what he requires to start with. As he proceeds with his work, he will find there are many accessories, such as a protractor, curves,

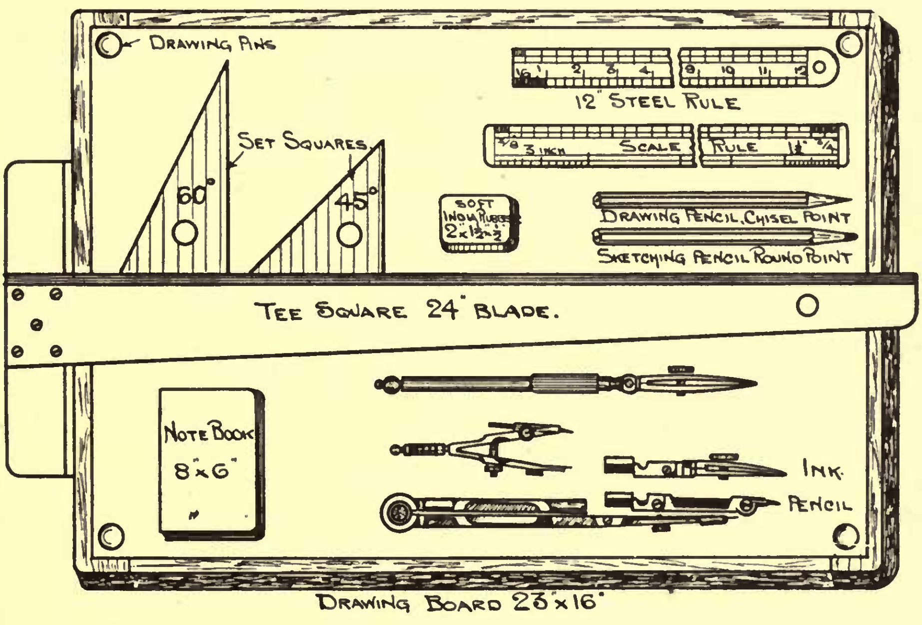


Fig. 1.—Apparatus required by Student.

more drawing instruments, slide rule, callipers, clinograph, micrometer, speed counter, etc., which will enable him to get through his work with greater rapidity.

Drawing board.
Tee square.
Drawing paper.
Large-headed drawing pins for holding paper down on the board.
Black-lead pencils: H.B., H., and H.H. grades.
Two set squares, 45° and 60°.
India-rubber.
Steel rule and scale rule.
Drawing instruments and note-book.

The first three items are usually supplied by the drawing office and by the evening school authorities, the remainder being supplied by the draughtsman or student himself.

It cannot be too often impressed upon the student that he must acquire

the habit of neatly and carefully recording his experiences, and the proper keeping of a class *note-book* is excellent practice in this. In addition to making notes, the engineer finds it necessary to make sketches of interesting and useful pieces of machinery, to tabulate data, and often to plot a rough curve to show readily how one quantity varies with another. Hence a note-book consisting largely of squared paper is most handy, lending itself extremely well to each of these requirements.

The cost of the above apparatus is altogether a question of quality, but they should be purchased from a first-class manufacturer, and care taken of them. The student will use his instruments in connection with other technical subjects, and should consider, when buying, that he is making a purchase which will be useful to him for a lifetime, and consequently buy the best class of material and instruments that he can afford, adding to them from time to time, and always bearing in mind that the capabilities of any workman are decidedly improved by the use of good tools. The safest thing a student can do, before purchasing, is to seek the advice of a competent draughtsman or teacher.

Set Squares.—Set squares vary greatly both in price and quality. Transparent celluloid ones are most useful, as they do not block out of sight any of the work on the paper. On the other hand, a careless use of the drawing pencil will lead to most inaccurate work, as in some lights the edges of the square are not too well defined, and the tendency is for the line being drawn to get away from the edge without being noticed. A pencil well sharpened, with a flat point, and properly used, obviates this difficulty. Two set squares will be found sufficient for all ordinary work—(1) a 45° square, and (2) a 60° square, the angles and proportions of which are shown in fig. 2.

Set squares are mainly used for drawing all lines perpendicular to the blade of the tee square. As either square may be used indiscriminately, and may also be used either hand, it is necessary that the right angle (90°) be accurate; otherwise the vertical lines will not all be parallel to each other. An easy test to see if the square is correct is to put it on the blade of the tee square, and with a firm, hard pencil draw a vertical line. Then turn the square over and see if the edge coincides with the line drawn. It should do so.

Set squares are used also for drawing lines parallel to each other and perpendicular to each other in any position on the board.

Protractor.—Is used for setting out angles from a centre. The best form for a student is that sold as a 6-inch rule (see fig. 2). It is a useful detail, but not much used in the drawing office, except in certain specialised work, such as the setting-out of valve motions and diagrams for steam engines, in which case one accurately divided, in the form of a circular ring, with a cross-bar carrying the centre, is the best.

Rule.—A good steel rule, one edge plainly marked in inches, subdivided into sixteenths, with a short length of 3 inches subdivided to thirty-seconds, and the other edge of the rule divided into millimetres, with main divisions every centimetre, is far better than one marked with a lot of fancy odd divisions, which only causes endless trouble and a complete waste of time to everybody making use of it.

Scale Rule.—Since it is obviously impossible to draw all objects full or natural size, we reduce them on drawings to some convenient size by using

scales, such as one-eighth, one-quarter, or half size. The definite scales to be used in any particular office are noted, and odd scales must not be used. A scale of half size is found by many to be misleading, and leads to mistakes by using the ordinary rule, and forgetting to multiply by 2.

For general work, an oval boxwood scale 12 inches long, plainly marked on the four edges thus:—

(1) 3 inches and $1\frac{1}{2}$ inches to the foot.
(2) $\frac{3}{4}$ inch " $\frac{3}{8}$ inch "
(3) 1 " " $\frac{1}{2}$ " "
(4) $\frac{1}{4}$ " " $\frac{1}{8}$ " "

is found most convenient and useful, and saves a lot of time. For the student, however, it is a most valuable mental training to acquire the habit of drawing

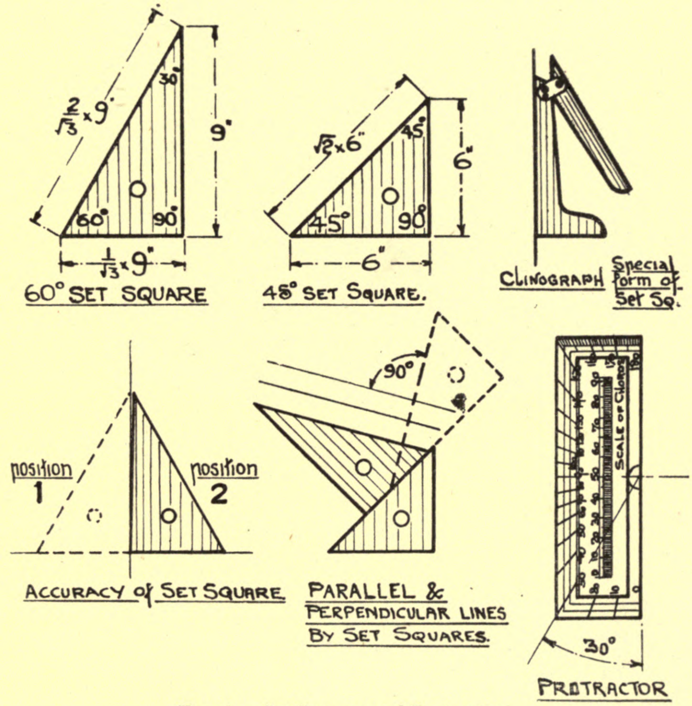


FIG. 2.—Set Squares and Protractor.

to scale from the edge of the ordinary steel rule. The scale to which a drawing is made must always be noted on the drawing, usually in the bottom left-hand corner.

Drawing Instruments.—To produce a drawing certain instruments are required, and skill in their use is necessary. As the quality of the work produced depends greatly upon the quality of the tools used, the question of what instruments to buy becomes most important. A man of moderate means should not go in for buying a highly finished box, packed with all sorts of instruments, many of which he will never make use of, but should confine

himself to the purchase of a few necessary instruments of good quality, adding to them as he goes along and becomes better acquainted with what he requires. By reference to fig. 1, a minimum set consists of:—

4½-inch compass with loose pencil and pen points.
Pencil spring bow.
Drawing pen.

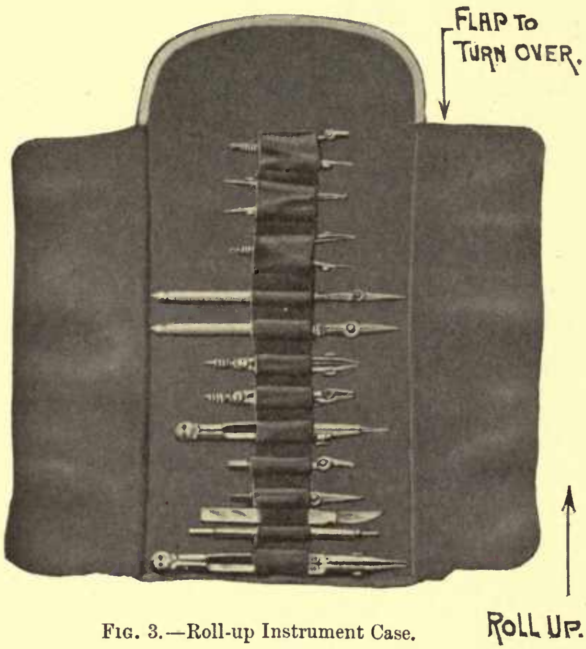


Fig. 3.—Roll-up Instrument Case.

To carry these about, use a roll-up case (best made of chamois leather), as shown in fig. 3.

Fig. 4.—Drawing Outfit.

A useful draughtsman's outfit in the way of tools and accessories is illustrated in fig. 4, and consists of:—

Drawing board and tee square. Box of instruments. Protractor. Sandpaper block. Pencil and ink erasers. Pen and pencils. Tin with slot-holes for erasures on tracing cloth. Rim speed counter. Spindle speed counter. Stop-watch. Two set squares. Inside and outside callipers. Steel square. Steel rule. Slide rule. Scale rule. Two-foot trammel or beam compasses, and note-book.

USEFUL DATA.

Decimal, and Millimetre Equivalents of Fractional parts of an Inch.

Fraction	Decimal	Milli/m.	F.	D.	m/m.	F.	D.	m/m.	F.	D.	m/m.
1-64	0·0156	0·397	17. 64	0·2656	6·747	33·64	0·5156	13·097	49. 64	0·7656	19·447.
1-32	·0312	0·794	9. 32	·2812	7·144	17. 32	·5312	13·494	25. 32	·7812	19·844
3. 64	·0468	1·191	19. 64	·2968	7·541.	35. 64	·5468	13·891.	51. 64	·7968	20·241.
1. 16	·0625	1·587	5. 16	·3125	7·937	9. 16	·5625	14·287	13. 16.	·8125	20·637
5. 64	·0781	1·984	21. 64	·3281.	8·334	37. 64	·5781.	14·684	53. 64	·8281	21·034
3. 32	·0937	2·381	11. 32	·3437	8·731	19. 32	·5937	15·081	27. 32	·8437	21·431
7. 64	·1093	2·778	23·64	·3593	9·128	39. 64	·6093	15·478	55. 64	·8593	21·828
1. 8.	·125	3·175	3. 8	·375	9·525	5. 8.	·625	15·875	7. 8	·875	22·225
9. 64	·1406	3·572	25. 64	·3906	9·922	41. 64	·6406	16·272	57. 64	·8906	22·622
5. 32	·1562	3·969	13. 32	·4062	10·319	21. 32	·6562	16·669	29. 32	·9062	23·019
11. 64	·1718	4·366	27. 64	·4218	10·716	43. 64	·6718	17·066	59. 64	·9218	23·416
3. 16	·1875	4·762	7. 16	·4375	11·112	11. 16	·6875	17·462	15. 16	·9375	23·812
13. 64	·2031	5·159	29. 64	·4531	11·508	45. 64	·7031	17·859	61. 64.	·9531	24·209
7. 32	·2187	5·556	15. 32	·4687	11·906	23. 32	·7187	18·256	31. 32	·9687	24·606
15. 64	·2343	5·953	31. 64	·4843	12·303	47. 64	·7343	18·653	63. 64.	·9843	25·003
1. 4.	·25	6·35	1. 2.	·5	12·7	3. 4.	·75	19·05	1	1·0	25·4

IMPERIAL STANDARD WIRE GAUGE.

Table of Equivalent Diameters in Decimals of an Inch and Millimetres.

No.	Decimals of an Inch.	M/m.	No.	Decimals of an Inch.	M/m.	No.	Decimals of an Inch.	M/m.
7/0	·500	12·700	13	·092	2·337	32	·0108	·274
6/0	·464	11·785	14	·080	2·032	33	·0100	·254
5/0	·432	10·973	15	·072	1·829	34	·0092	·233
4/0	·400	10·160	16	·064	1·626	35	·0084	·213
3/0	·372	9·449	17	·056	1·422	36	·0076	·193
2/0	·348	8·839	18	·048	1·219	37	·0068	·172
0	·324	8·229	19	·040	1·016	38	·0060	·152
1	·300	7·620	20	·036	·914	39	·0052	·132
2	·276	7·010	21	·032	·813	40	·0048	·122
3	·252	6·401	22	·028	·711	41	·0044	·111
4	·232	5·893	23	·024	·610	42	·0040	·101
5	·212	5·385	24	·022	·559	43	·0036	·091
6	·192	4·877	25	·020	·508	44	·0032	·081
7	·176	4·470	26	·018	·457	45	·0028	·071
8	·160	4·064	27	·0164	·416	46	·0024	·061
9	·144	3·658	28	·0148	·376	47	·0020	·0508
10	·128	3·251	29	·0136	·345	48	·0016	·0406
11	·116	2·946	30	·0124	·315	49	·0012	·0305
12	·104	2·642	31	·0116	·294	50	·0010	·0254

1 mil = one-thousandth part of an inch.

Metric Measures.

The metric unit of length is the *metre* = 39·37 inches.
1 inch = 2·54 centimetres = 25·4 millimetres.
The metric unit of mass or weight is the *gram* = 15·432 grains.
1 lb. = 454 grams, and 1 kilogram = 1000 grams = 2·2046 lbs. = 2 lbs. 3 ozs.
The metric unit of volume is the *litre*; it is the capacity of a cubic decimetre.
1 litre of water = 1·76 pints = 2·202 lbs. at 62° F.

The following prefixes are used for subdivisions and multiples :—

Milli = $\frac{1}{1000}$, Centi = $\frac{1}{100}$, Deci = $\frac{1}{10}$, Deca = 10, Hecto = 100, Kilo = 1000, Myria = 10,000.

Mensuration.

Triangle.—Base b and height h. Area $= \frac{1}{2} \times b \times h$.

Circle.—Circumference = 3·14 × diameter.

$$\text{Area} = 3{\cdot}14 \times \text{radius} \times \text{radius} = \pi \times r^2$$
$$= {\cdot}7854 \times \text{diameter} \times \text{diameter} = \frac{\pi}{4} \times d^2.$$

3·1416, or π, is always known as *Pi*, the sixteenth letter in the Greek alphabet.

Ellipse.—Having semi-axes a and b.

$$\text{Circumference} = \tfrac{1}{2}\pi\left\{a + b + \sqrt{2(a^2+b^2)}\right\} \text{nearly.}$$
$$\text{Area} = \pi \times a \times b, \text{ nearly.}$$

Sphere.—Radius r. Surface $= 4 \times \pi \times r^2$. Volume $= \frac{4}{3} \times \pi \times r^3$.

Irregular Area.—(1) By using squared tracing paper. (2) By Simpson's rule.

Simpson's rule.—If necessary, divide the area into two by drawing a diameter, and consider as two areas.

Divide the base into an even number of equal parts, say 10, distance apart d.

At each erect a perpendicular cutting the curve and called the ordinate. Let the length be called h, and number from 1 to 11; then

$$\text{Area} = \frac{d}{3}\left\{h_1 + h_{11} + 4(h_2 + h_4 + h_6 + h_8 + h_{10}) + 2(h_3 + h_5 + h_7 + h_9)\right\}.$$

Polygon.—A regular polygon can be inscribed in a circle, and can have a circle inscribed in it, the two circles having the same centre.

We have equilateral triangle 3 sides, square 4, pentagon 5, hexagon 6, heptagon 7, octagon 8, nonagon 9, decagon 10 sides.

The angle at the centre of a polygon is that contained by two lines drawn to the centre from two consecutive corners, and $= \frac{360}{\text{number of sides}}$. This gives a ready method of setting out a regular polygon, using a protractor.

Greek Letters.

The student will not do very much reading before finding that very often quantities are represented by letters taken from the Greek alphabet, and will therefore do well to obtain a general idea of these letters.

α	A	Alpha	A	ν	N	Nu	N
β	B	Beta	B	ξ	Ξ	Xi	X
γ	Γ	Gamma	G	ο	O	Omicron	O short
δ	Δ	Delta	D	π	Π	Pi	P
ε	E	Epsilon	E short	ρ	P	Rho	R
ζ	Z	Zeta	Z	σ ς	Σ	Sigma	S
η	H	Eta	E long	τ	T	Tau	T
θ	Θ	Theta	Th	υ	Υ	Upsilon	U
ι	I	Iota	I	φ	Φ	Phi	Ph
κ	K	Kappa	K	χ	X	Chi	Ch
λ	Λ	Lambda	L	ψ	Ψ	Psi	Ps
μ	M	Mu	M	ω	Ω	Omega	O long

EXAMPLES FOR TRACING

Drawing No. 1.

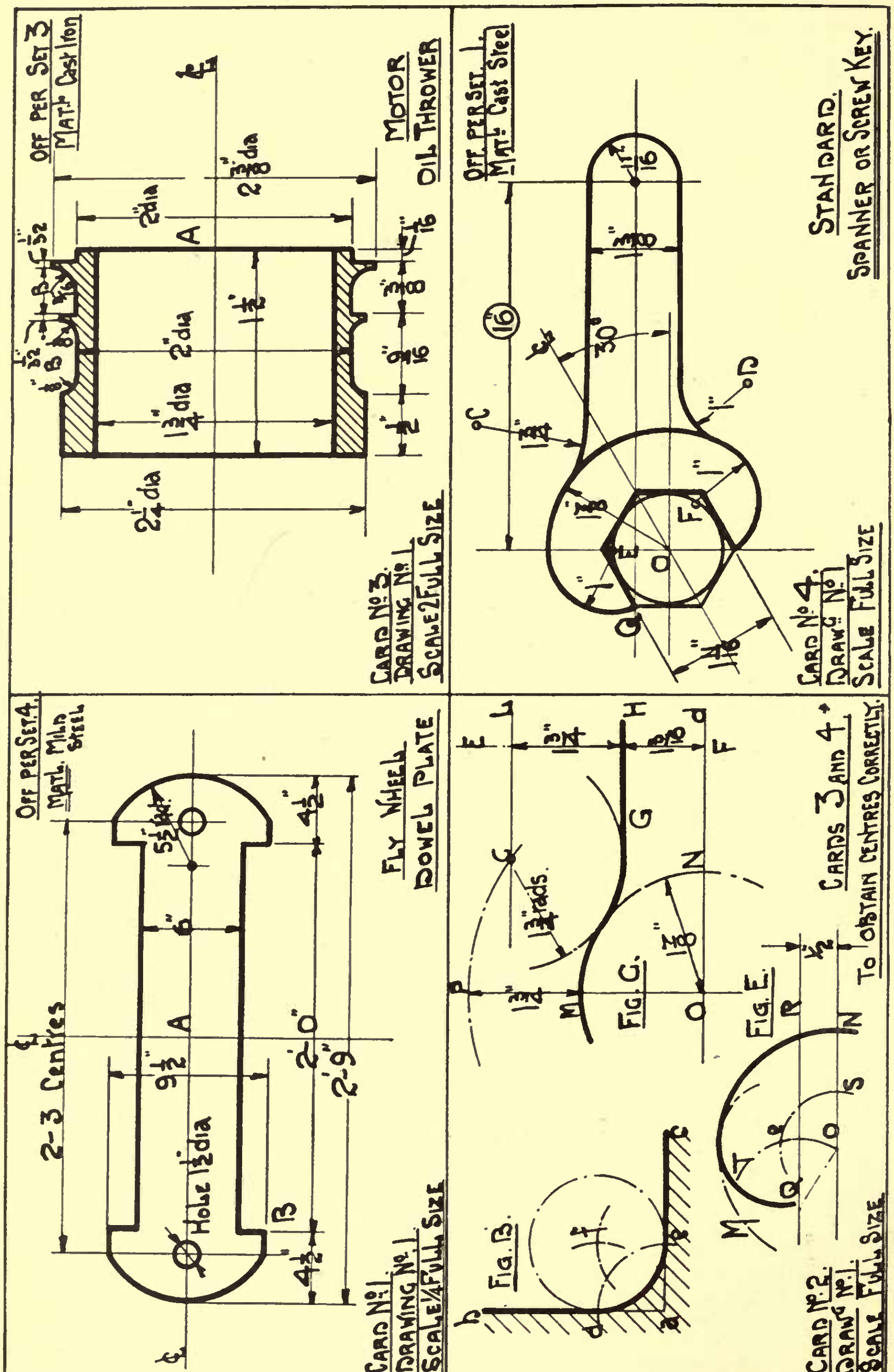
A YOUTH making a start in a drawing office will usually find that for some time he will be occupied with making tracings from the pencil drawings of a more experienced draughtsman. Such a set of drawings, even if obtainable, would be too complicated for the student with limited time at his disposal. The setting out of the following examples will furnish practice in drawing lines, joining up lines to curves, curves to curves, etc., and will enable the student to become familiar with the use of his instruments, and will produce examples which will afford experience in tracing immediately they are completed.

Drawing No. 1 consists of four cards, the detailed description of which follows immediately. The drawing should be completely finished off with all dimensions and lettering, as shown on next page, the drawing number being put on the top right-hand and bottom left-hand corners in large block figures about $\frac{1}{2}$ inch deep, and the title in the bottom right-hand corner in neat block letters between lines drawn $\frac{5}{16}$ inch apart. The drawing should be signed with name and date, and care taken of it until it is required for tracing purposes.

The way in which the sheet of paper should be fixed to the board depends upon its ultimate use. Thus, if on the sheet it is intended to scheme and set out the design of an important machine, it would be damped by dipping in water, then glued by a half-inch margin down to the board, and left overnight in a horizontal position to dry. In the morning the sheet is tightly stretched, and will remain so for an indefinite period, with the result that, at any time, dimensions can be scaled off from it with accuracy. If required for a less important purpose, the sheet is simply tacked down with ordinary tacks, or, better still, with drawing pins.

Having a sheet of drawing paper 22 by 15 inches pinned on the board, first draw a margin or border round it, half an inch from the edge, leaving a working space of 21×14 inches. Divide this up into four equal cards, by one horizontal and one vertical line. Each card will thus measure $10\frac{1}{2} \times 7$ inches.

In the pencil drawing, all centre and dimension lines must be full faint lines, and not broken lines. All dimensions should be marked off direct with the pencil from the edge of the rule, and not transferred with dividers. The arrow-heads terminating the dimension lines must be made with the barbs lying close to the shank, and not spread out. Practise a neat method of writing and figuring, and, remembering that a drawing must be made right, do not hesitate to use your india-rubber, well called a draughtsman's best friend.



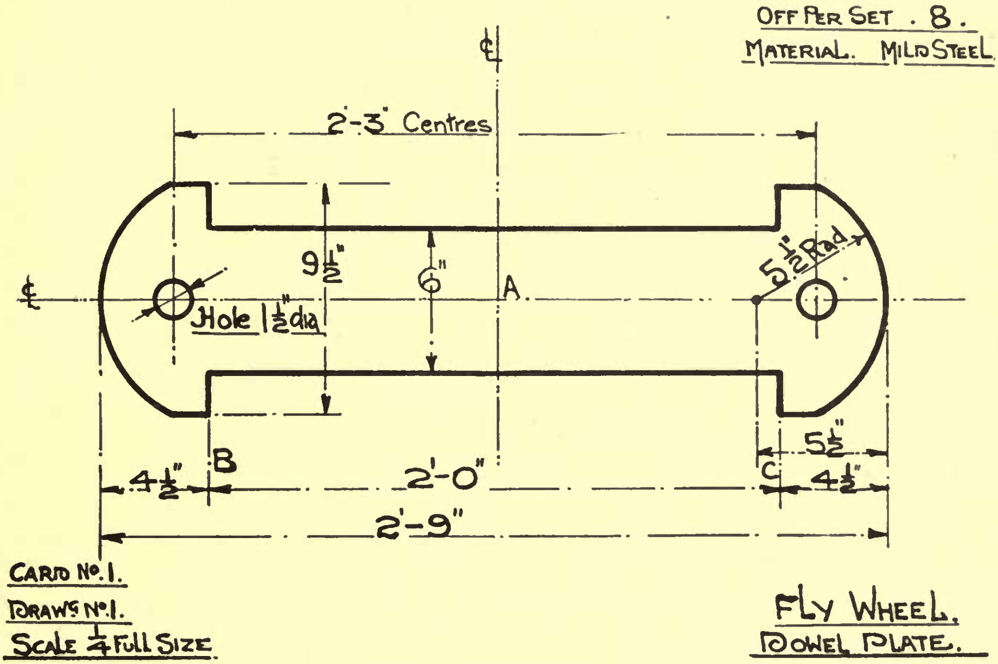
EXAMPLES FOR TRACING

DRAWING No. 1.

It sometimes seems a pity to clear out the result of some hours' work, but if it is not drawn correctly to dimensions, it should be erased and be drawn correctly.

Card No. 1.—Shows the outline of a dowel plate, used for fixing the rim of a fly-wheel when it is built from segments (refer to Drawing No. 22 B).

First draw in the centre lines CL, fixing the point A. The detail is symmetrical about these centre lines. Fill in from the dimensions. It is clearly impossible on your sheet to set out the dowel plate full size to the actual dimensions; hence every dimension given must be divided by four, and the result used for setting out the drawing. Thus, while BC is 2 feet actual



size, in our drawing it will be represented by a length of 6 inches. The drawing so obtained is said to be drawn to a scale of ¼ natural size, ¼ full size, or 3 inches to the foot, by which we mean that 3 inches on our drawing is equal to 1 foot on the actual detail.

Card No. 2.—The object of the work on this card is to explain the geometrical methods used to obtain correctly the centre B on Card No. 3, and the centres C, D, E, and F on Card No. 4.

Fig. B. Two surfaces meet at right angles: to fillet off the sharp corner so formed.—Draw the lines *ab*, *ac*, meeting at right angles. To draw, say, a 1-inch circle, to touch *ab* and *ac* and so fillet off the corner:—Take on the compass a length equal to the radius required (in this case half an inch). With *a* as centre and this radius mark off *ad* and *ae*. With the same radius take *d* and *e* as centres in turn, and draw the two arcs cutting in *f*. Then *f* is the centre for the radius forming the fillet.

Fig. C. To draw a circle to touch a given circle and a given straight line.—From a centre O, with a radius OM equal to $1\frac{7}{8}$ inches, draw the arc MN. Draw GH parallel to the centre line O*d*. To find the centre C of a circle $1\frac{3}{4}$ inches radius which touches both these:—

From any point F in O*d* draw the perpendicular FE, and by its aid draw CL parallel to GH and $1\frac{3}{4}$ inches from GH. Any circle with its centre on CL and $1\frac{3}{4}$ inches radius will touch GH.

From M make MP equal to $1\frac{3}{4}$ inches, and with centre O draw the arc PC. Any circle with its centre on PC and radius $1\frac{3}{4}$ inches will touch the arc MN. The point of intersection C gives the centre of a circle $1\frac{3}{4}$ inches radius, which touches the given circle and straight line.

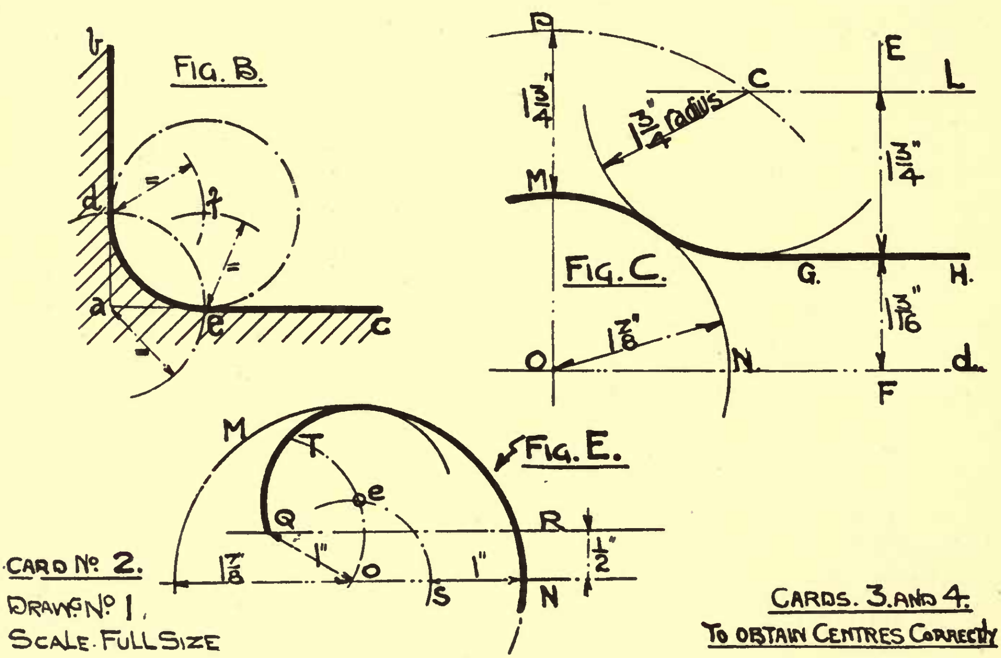
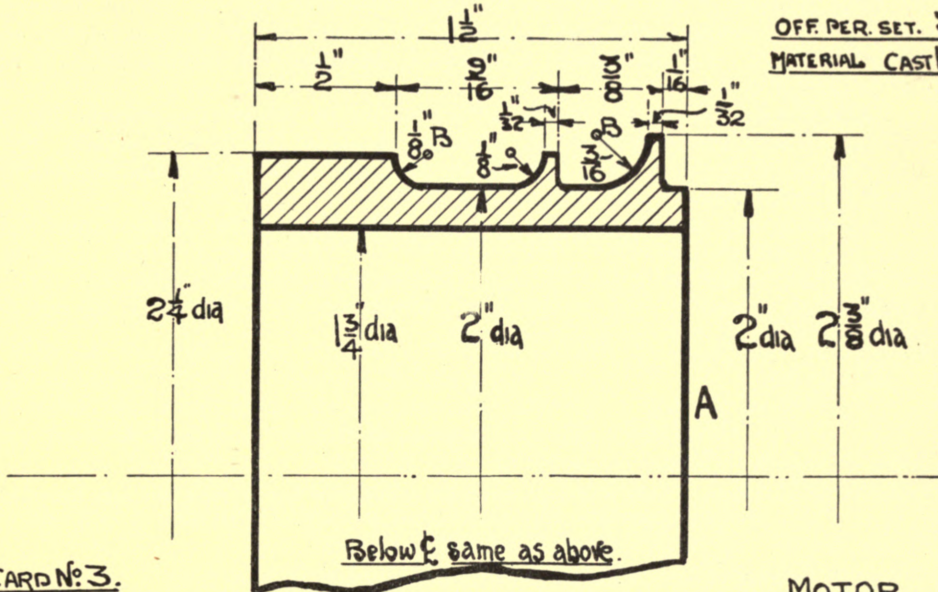


Fig. E. To draw a circle to pass through a given point and touch a given circle.—From O as centre draw the circle MN, radius $1\frac{7}{8}$ inches. Fix the point Q by drawing QR parallel to the centre line ON, $\frac{1}{2}$ inch from it, and making OQ equal to 1 inch. To find the centre *e* of a circle, say 1 inch radius, which will pass through Q and touch the arc MN:—

From N along NO mark off a length of 1 inch, giving S. With O as centre, radius OS, draw the arc S*e*. With Q as centre and the radius 1 inch draw the arc T*e*. The intersection *e* of these two arcs gives the centre of the circle, 1 inch radius, which passes through Q and touches MN.

Card No. 3.—Shows the sectional outline of an oil-thrower, used mainly for electric motors. They are fixed on the shaft, one on each side of a bearing, and prevent oil from the bearing creeping along the shaft by flinging it off, due to centrifugal force. The side A goes next the bearing.

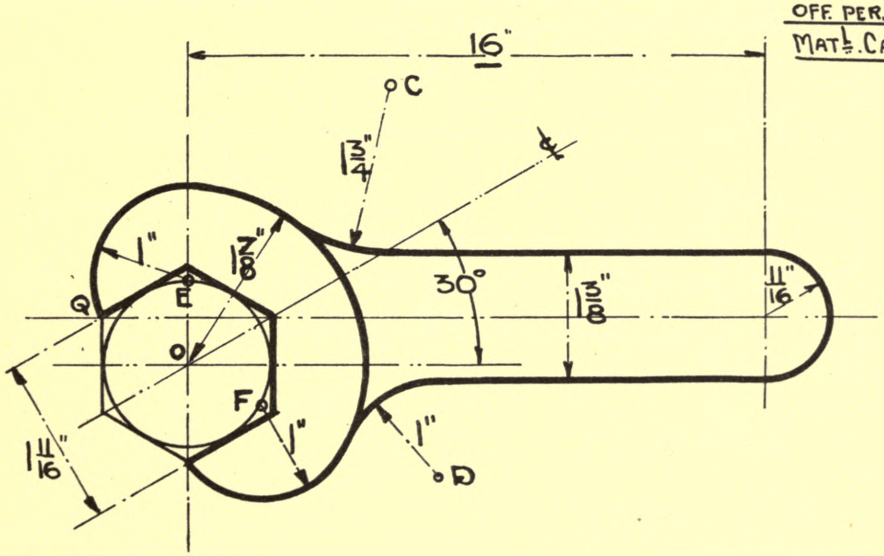
OFF. PER. SET. 3
MATERIAL CAST IRON



CARD No. 3.
DRAWG No. 1.
SCALE TWICE FULL SIZE

MOTOR
OILTHROWER.

OFF. PER. SET. 1
MATL. CAST STEEL.



CARD No. 4.
DRAWG No. 1
SCALE FULL SIZE

STANDARD
SPANNER OR SCREW KEY

That portion of the detail above the centre line only is shown, but on making the drawing it must be completed below the centre line, as shown in Drawing No. 1. For the correct method of obtaining the centres B, refer to fig. B, Card No. 2.

Card No. 4.—Shows the outline of a spanner or screw-key, suitable for a one-inch Whitworth standard nut. The length of the handle is 16 inches. For the purpose of drawing, make it 6 inches long, and indicate that the dimension is not correct to scale by drawing a line under it.

In setting out the example, commence with the centre O, and draw the circle $1\frac{11}{16}$ inches diameter. With the 60° set square set out the hexagon jaw, thus fixing the point Q. Through Q draw the horizontal centre line of the handle, then proceed to fill in the detail, obtaining the centres C, D, E, and F as shown in fig. C and fig. E, Card No. 2.

Examples—

1. When making a drawing we use a scale determined by the size of the detail. Set out a scale of 6 inches = 1 foot to read up to 2 feet.

   Note.—Use a proper geometrical construction for dividing the first 6 inches into 12 parts, to represent inches, and then for dividing at least one of these parts into four to represent $\frac{1}{4}$-inches.

2. Set out a scale of quarter full size to read up to 4 feet.
3. Set out a scale of half full size to read up to 30 centimetres.
4. Set out a circle $1\frac{1}{2}$ inches radius touching a circle 3 inches radius, (*a*) externally, (*b*) internally.
5. Draw two circles, 2 inches and $1\frac{1}{2}$ inches diameter respectively, with their centres $2\frac{1}{2}$ inches apart. Draw geometrically the four tangent lines touching both circles.

EXAMPLES FOR TRACING.

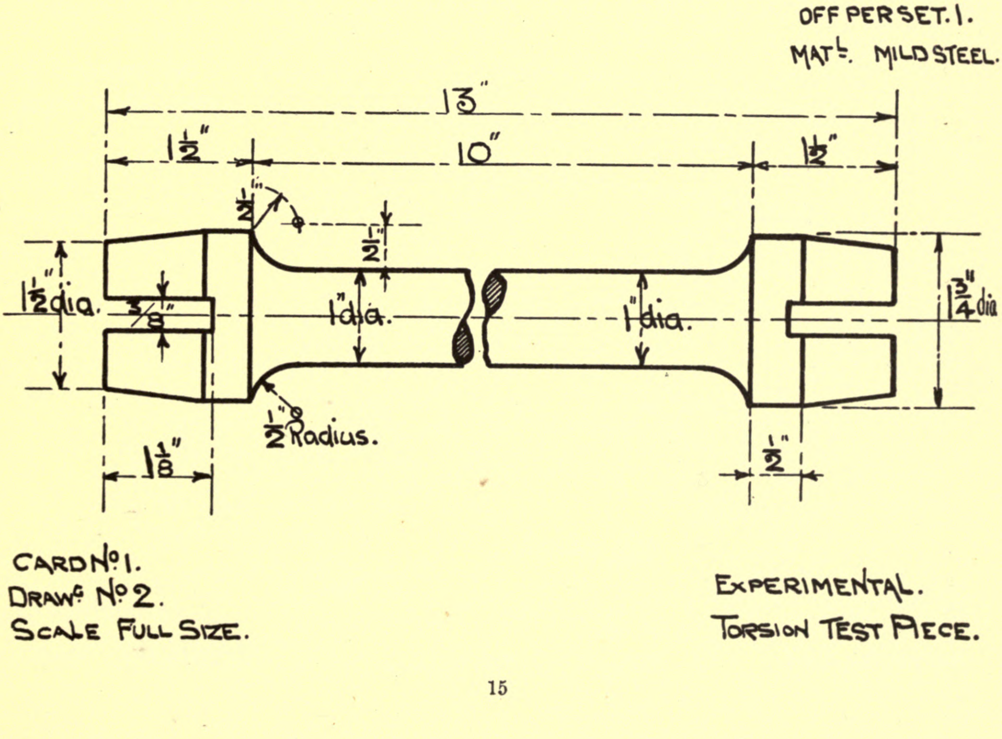
Drawing No. 2.

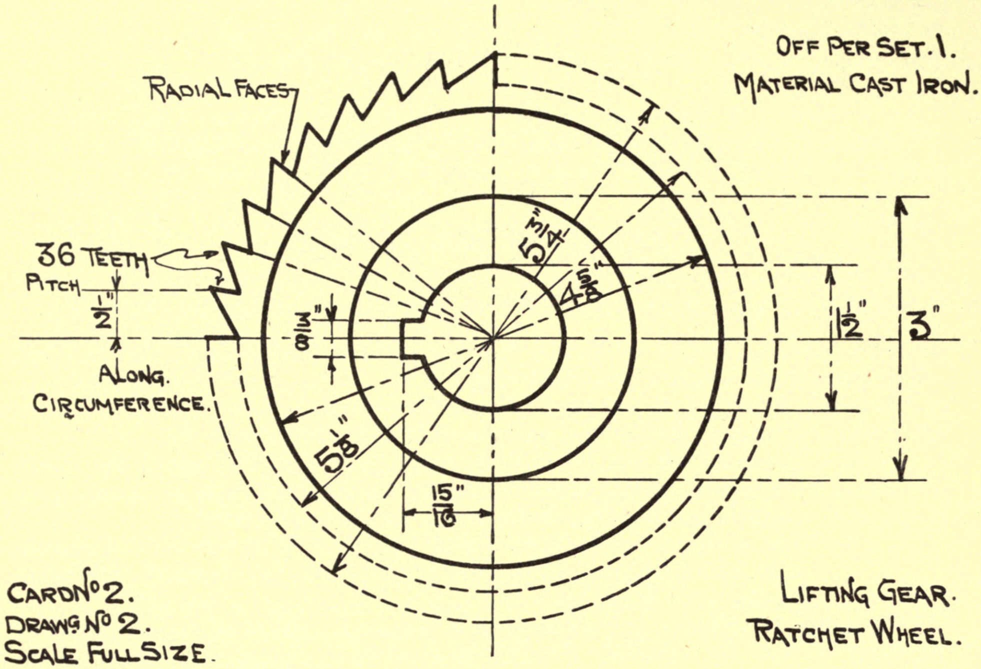
MAKE a drawing of the following four cards, fully dimensioned and finished off in exactly the same way as Drawing No. 1.

The important points to remember are:—

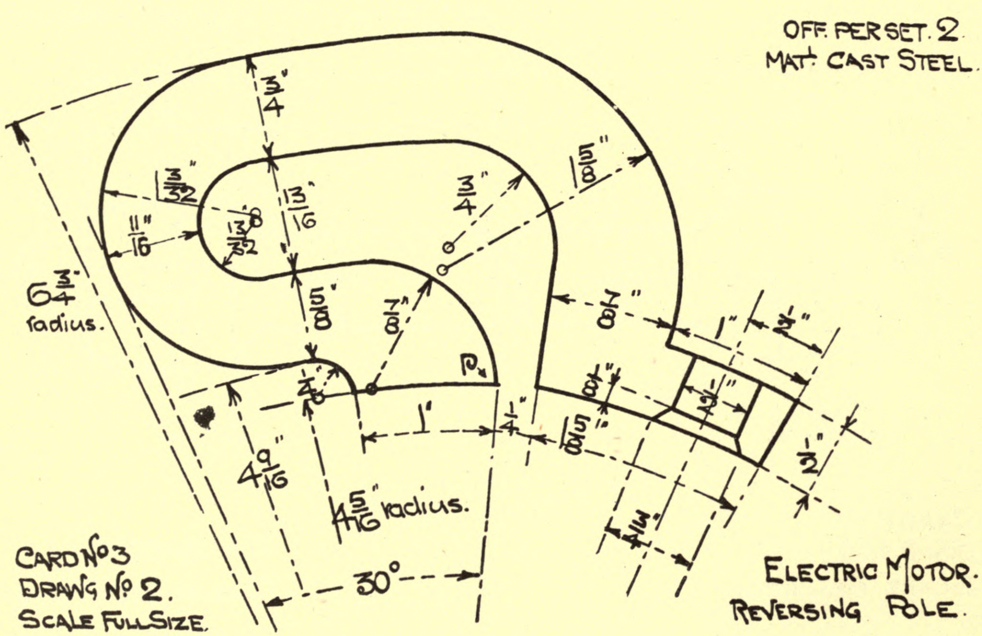
1. All centre and dimension lines to be faint full lines.
2. The centre for a curve is to be found geometrically before the curve is drawn. The centre should not be obtained by trial; and, above anything else, do not sketch in the curve freehand.
3. When a centre has been obtained, a small ring round it will enable it to be found at a glance, and prove very useful when you come to trace the drawing.

Card No. 1.—Shows the outline of a piece of mild steel, as arranged to undergo a test for torsion. Shafts transmitting energy are subjected to





OFF PER SET. 1.
MATERIAL CAST IRON.
RADIAL FACES
36 TEETH
PITCH
1/2"
ALONG CIRCUMFERENCE.
3/8"
5 3/4"
4 5/8"
5 1/8"
15/16"
1 1/2"
3"
CARD No 2.
DRAWG No 2.
SCALE FULL SIZE.
LIFTING GEAR.
RATCHET WHEEL.

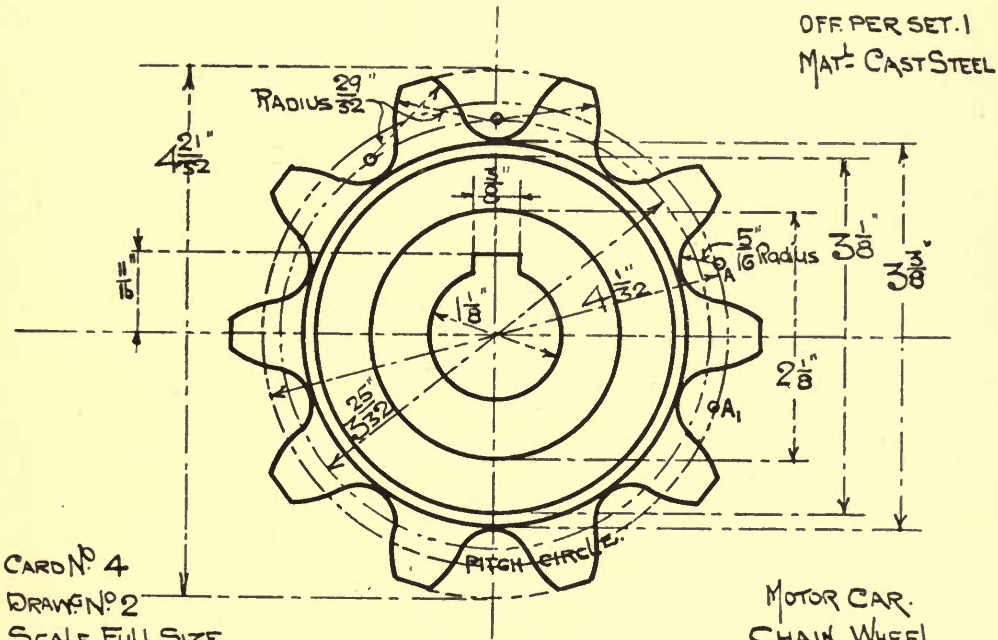


OFF. PER SET. 2
MATL CAST STEEL.
3/4"
3/32"
13/16"
11/16"
13/32"
3/4"
1 5/8"
6 3/4" radius.
5/8"
7/8"
3/4"
R
1"
1/4"
5/8"
1 1/2"
1 1/2"
1/2"
1/4"
4 9/16"
4 5/16" radius.
30°
CARD No 3
DRAWG No 2.
SCALE FULL SIZE.
ELECTRIC MOTOR.
REVERSING POLE.

twisting, and, in order to obtain some knowledge of the properties and behaviour of any metal when in such a state of stress, pieces are cut from it, shaped as indicated, and subjected to known torsional stresses.

The slot at one end serves to hold that end rigid in a fixed head; the slot at the other end enables the stress to be applied so as to twist the bar. Whilst doing this the necessary observations are made.

Card No. 2.—Shows a ratchet wheel. This is rigidly keyed to a shaft, and a pawl engaging the teeth allows the shaft to rotate in one direction only. The wheel has thirty-six teeth, half-inch pitch, on the rim or circumference, which therefore has a length of 18 inches. The diameter, which is circumference ÷ 3·14, is 5·73 inches,—say $5\frac{3}{4}$ inches.



Card No. 3.—Shows the reversing pole of the field-magnet of an electric motor. Set out the detail iu the upper right-hand card on the sheet. Commence by fixing the centre from which the large radii are drawn. After drawing in these arcs, work away from the point P. A detailed explanation of how to obtain the various centres is not offered, but the student should endeavour to obtain geometrically the centre of a circle, before drawing it in.

Card No. 4.—Shows the outline of the chain-wheel of a motor. It has ten teeth. To set these out, first fix the ten centres A, A_1, etc., on the pitch circle. This may be done as follows:—

1. The angle at the centre of a circle is 360 degrees.
   By means of a protractor set out ten radial lines from the centre, the angle between any two being 36 degrees.
2. Diameter of pitch circle $= 4\frac{1}{32}$ inches.
   Circumference of pitch circle $= 4\frac{1}{32} \times 3·14 = 12·66$ inches.

So that pitch AA_1 along the circumference is one-tenth of this, or 1·266 inches.

Stepping this round the circumference with a pair of dividers, the distance marked off is really the length of the straight line or chord joining AA_1, and this is shorter than the arc AA_1. Therefore take a length of $1\frac{1}{4}$ inches on the compass, and step round the circle; adjust the compass, and step round again until the circumference is divided into ten equal parts.

Example.—For each detail convert the dimensions into millimetres, and show them by red figures under the ordinary dimensions. Use the table on page 7.

EXAMPLES FOR TRACING.

Drawing No. 3.

It is absolutely essential that the student be thoroughly well able to draw lines, to figure, and to write neatly, and also be well acquainted with his instruments, before attempting work which involves a knowledge of projection. It will thus be found advantageous to continue on the lines of previous work, setting out the following four cards, and producing a drawing exactly as in the last two examples.

Card No. 1.—Gives useful geometrical constructions.

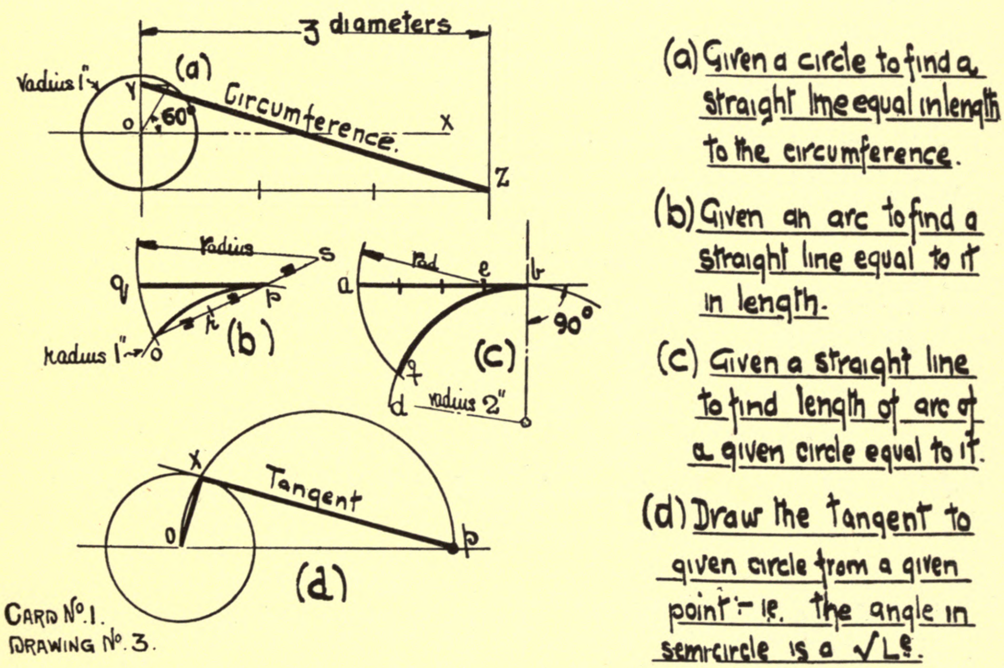


Fig. (a).—For the purpose of setting out, take a circle 1 inch radius through the centre O, draw a line at 60° to the horizontal, to cut the circumference in a point, through which draw a parallel to OX to cut the vertical line in Y. Measure the length YZ, and see how it agrees with the rule—

$$\text{Circumference} = \pi \times \text{diameter}.$$

From the properties of triangles, calculate what length YZ should be, and write down your results.

Fig. (*b*).—OP is a given arc of a circle. To find a straight line equal to it in length :—

From *p* draw the tangent *pq*, also the chord *po*. Bisect *po* in *r*, continue *op*, and make *ps* equal to *pr*. With *s* as centre, *so* as radius, draw the arc to cut the tangent in *q*. Then *qp* is equal in length to the arc *op*.

In setting out, take a circle 1 inch radius, make the chord *op* equal to the radius—that is, the arc *op* is one-sixth of the circumference. Measure *qp*. Write down the result. Check it by arithmetic.

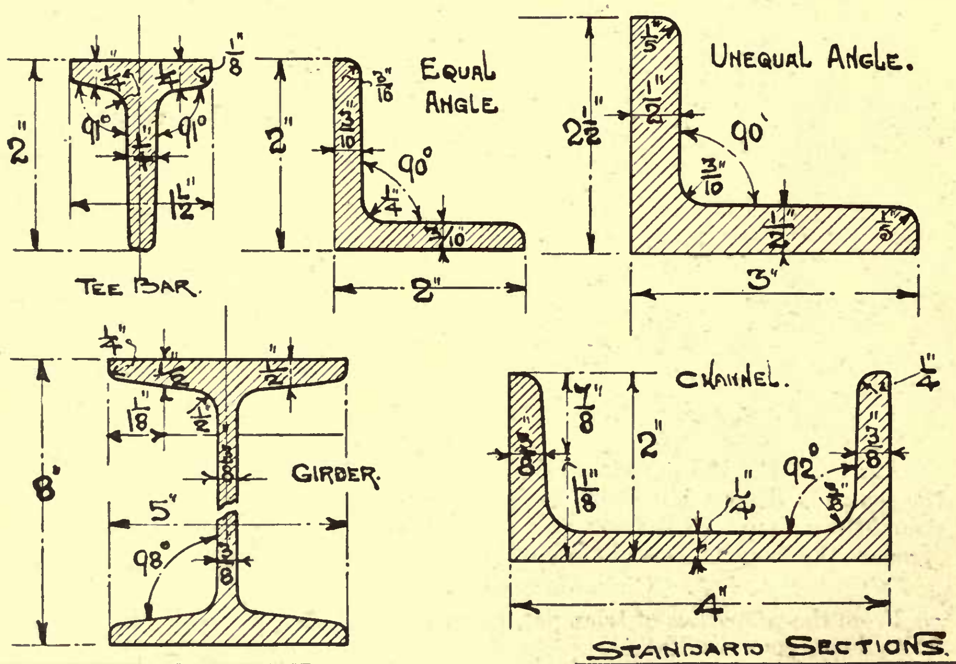
Fig. (*c*).—In setting out, draw a line *ab* 2·1 inches long. Draw the tangent circle *bd* with a 2-inch radius. To set off along the arc *bd* a length equal to the straight line *ab* :—

Divide *ab* into four equal parts. With *e* as centre, radius *ea*, draw an arc to cut the circle in *f*. Then *bf* is the arc required. Show that, with the dimensions taken, the chord *bf* should equal the radius of *bd*, *i.e.* 2 inches. Try if this is so.

Fig. (*d*).—Shows the method of drawing a tangent to a circle from a given point *p*. A semicircle is drawn on *op* as diameter, cutting the given circle at X. Then X*p* is the required tangent. The construction is based on the fact that the angle between any two chords, each having one end at the ends of the semicircle and meeting at a common point on the circumference, is a right angle. The angle in a semicircle is a right angle.

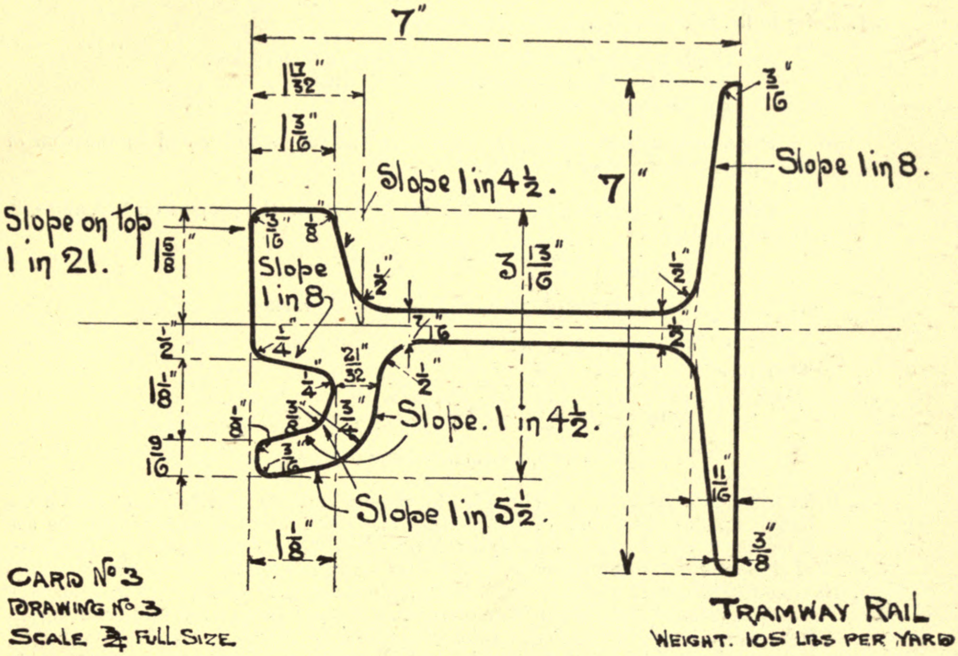
Card No. 2.—Set out full size the standard sections of tee, girder, channel, and angle irons shown.

In making use of similar sections of material in any work, the student must be careful to use only those sections actually rolled by the makers, and should refer to makers' or merchants' lists; also should not hesitate to stretch a point, if by so doing he can make use of an immediate stock size.

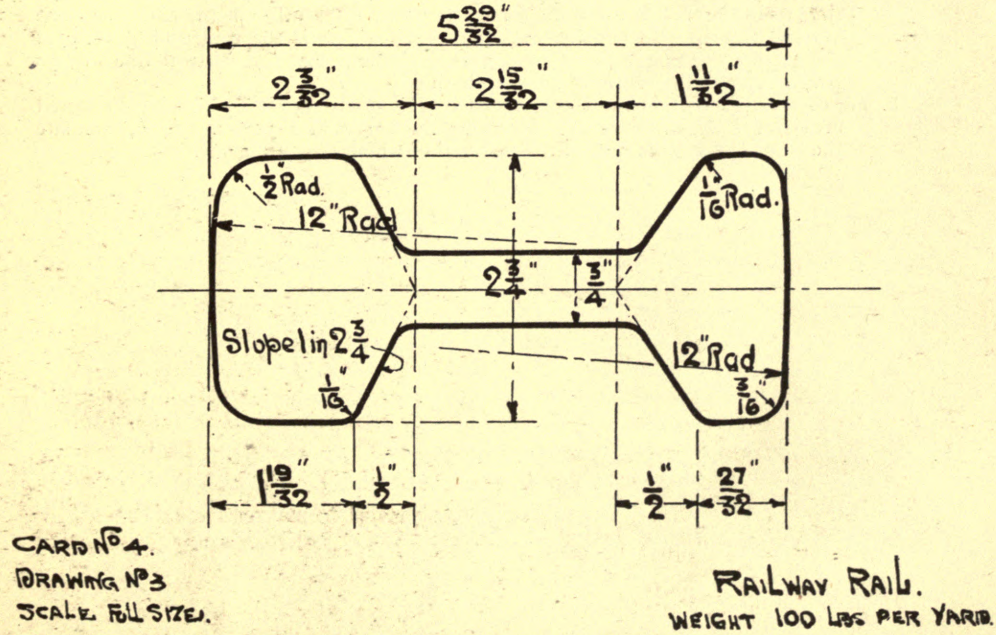


CARD No. 2. DRAWG No. 3.

Card No. 3.—Shows an English standard section of a tramway rail having a weight of 105 lbs. per yard. Set out to a scale of three-quarters full size.



Card No. 4.—Gives the section of a standard railway rail, weight 100 lbs. per yard. The setting out of Cards Nos. 3 and 4 is left entirely to the student, but no great difficulty should be experienced.



Examples—

1. Refer to fig. (*a*), Card No. 1, and its description.

   Circle 2 inches diameter. Circumference 6·28 inches.
   By construction: Circumference = inches.
   By calculation we have

   For a right-angle triangle, the square on the long side is equal to the sum of the squares on the other two sides.

   Take the 60° triangle (set square): the sides are in the proportion 1, 2, and $\sqrt{3}$. In the diagram,

   Radius = 1 inch.

   Vertical side of large triangle $= 1 + \frac{\sqrt{3}}{2}$ inches.

   Base = 3 diameters = 6 inches.

   Therefore

   $$\text{Long side} = \sqrt{6^2 + \left(1 + \frac{\sqrt{3}}{2}\right)^2} = \sqrt{36 + 3{\cdot}48}$$

   $$= 6{\cdot}28, \text{ or circumference.}$$

2. Refer to fig. (*b*), Card No. 1. The side of a regular hexagon inscribed in a circle has a length equal to the radius of the circle. Therefore, taken as an example, the arc cut off by a chord equal to the radius is one-sixth of the circumference. Diameter of circle 2 inches circumference, 6·28 inches. Length of arc, 1·04 inches.
3. Having the standard sections, Card No. 2, plotted out full size, find in each case the area, either by putting a piece of squared tracing paper over, and counting up the squares, or by calculation. Take a length of 12 inches and find the volumes. Taking the weight of the material as 0·28 lbs. per cubic inch, express the weights of the different sections in lbs. per foot.
4. Cut out full size in heavy paper or cardboard the rail sections, Cards Nos. 3 and 4. In each case, find the centre of gravity of the section—that is, the point about which the section will balance. Do this by the method of two suspensions; *i.e.* pin the section up on a vertical board so that it can oscillate freely, draw on the section the vertical line through the point of suspension (use a plumb bob to get this); pin the section up in the same way about some other point, and where the vertical line in this position cuts the previous one is the centre of gravity of the section. Pin up by other points, and show that the vertical line always passes through the centre of gravity obtained.
5. For each rail section, obtain the sectional area in square inches by drawing a squared area over it and counting up. Knowing the weight of 1 yard in length, calculate the weight of a cubic inch of the material of which they are made.

§ 2.—TRACING.

Use of a Tracing.—In earlier days a drawing was made on good-quality drawing paper, and when completed it was carefully inked in with Indian ink rubbed down from the solid stick, the centre lines drawn in, in red, the dimension lines in blue, and dimensions in black. Any future alterations were noted in red, and the drawing thus finished off was kept as a record. Copies of it to be sent out of the works were made on oiled semi-transparent paper called tracing paper. For the use of workmen in the shops, tracings were made on semi-transparent starched and glazed linen called tracing cloth.

Both kinds of tracing are expensive to make, as they occupy considerable time on the part of a tracer in the drawing office. The result was that shop tracings were in use long after they were in a most dirty condition, leading to endless waste of time in trying to read them, and great possibility of making mistakes, or the need for referring to the drawing office to see the record or original drawing.

Modern Use of Tracings.—Present-day procedure is somewhat as follows. The drawing is finished off by the draughtsman, who should waste no time in making it ornamental, simply making it plain, complete, and easy to read. It is then passed on to a tracer, who makes an accurate copy on tracing cloth, which copy is then passed on, together with the drawing, to a leading draughtsman, called a checker, who examines it to see that it is in accordance with the rules of the office, that it is drawn correctly, and that it does not contain any mistakes. After this checking the original drawing is officially destroyed, and the tracing is now ready for photo-print copies to be taken from it, which copies are used as explained in the next section.

Hints on Tracing.—

1. Do not attempt to save ink. Line in the detail with good, solid, firm lines, making the dimension and centre lines about half as thick.
2. Make your tracing on the dull side of the cloth: the ink runs more easily, and mistakes can be scrubbed out (by means of ink eraser) more readily, and with less injury to the surface. On the other hand, if the tracing is used as the drawing-office record for general reference, it will not wear out so quickly, and will not get so dirty, if the tracing is made on the glazed or glossy side.
3. After making an erasure or cleaning a tracing with india-rubber, restore the surface by rubbing with powdered French chalk.
4. Before commencing the tracing, try a few lines on the edge of the tracing cloth. It may be found that the ink tends to gather in

globules, and does not leave the lines with firm edges. This is due to the greasy surface of the cloth, to overcome which, rub the surface of the cloth with a duster and, preferably, powdered French chalk. In the absence of French chalk, ordinary chalk powdered will do.

5. After drawing a line, be careful to see that it is dry before sliding your tee square, set square, or arm over it.
6. Draw all lines from left to right, and be careful that the drawing pen does not cut through the cloth.
7. It is usual to put in all curves first, by aid of the ink compass, because it is so much easier to run a line to or from a curve than to join a curve to an existing straight line neatly.
8. If you are unlikely to finish your tracing before leaving it overnight, do not put in more curves than you can joint up before leaving, and finish off that portion of the detail you are engaged on. The tracing cloth will expand and buckle during the night, and may cause you trouble if you fail to do this. Leave your tracing on your board, and note its appearance next class meeting.

Fig. 5.—Illustrates a few points often required during tracing.

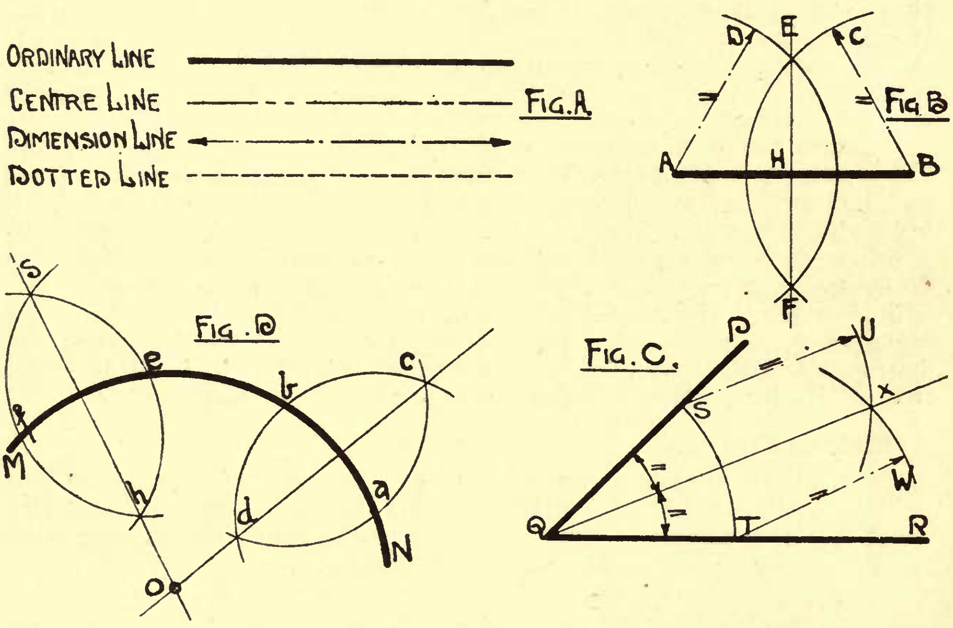


FIG. 5.

Fig. A.—Shows the usual class of lines to use when tracing. Sometimes tracings are made with centre lines in red, dimension lines in brown; this

To face page 24.

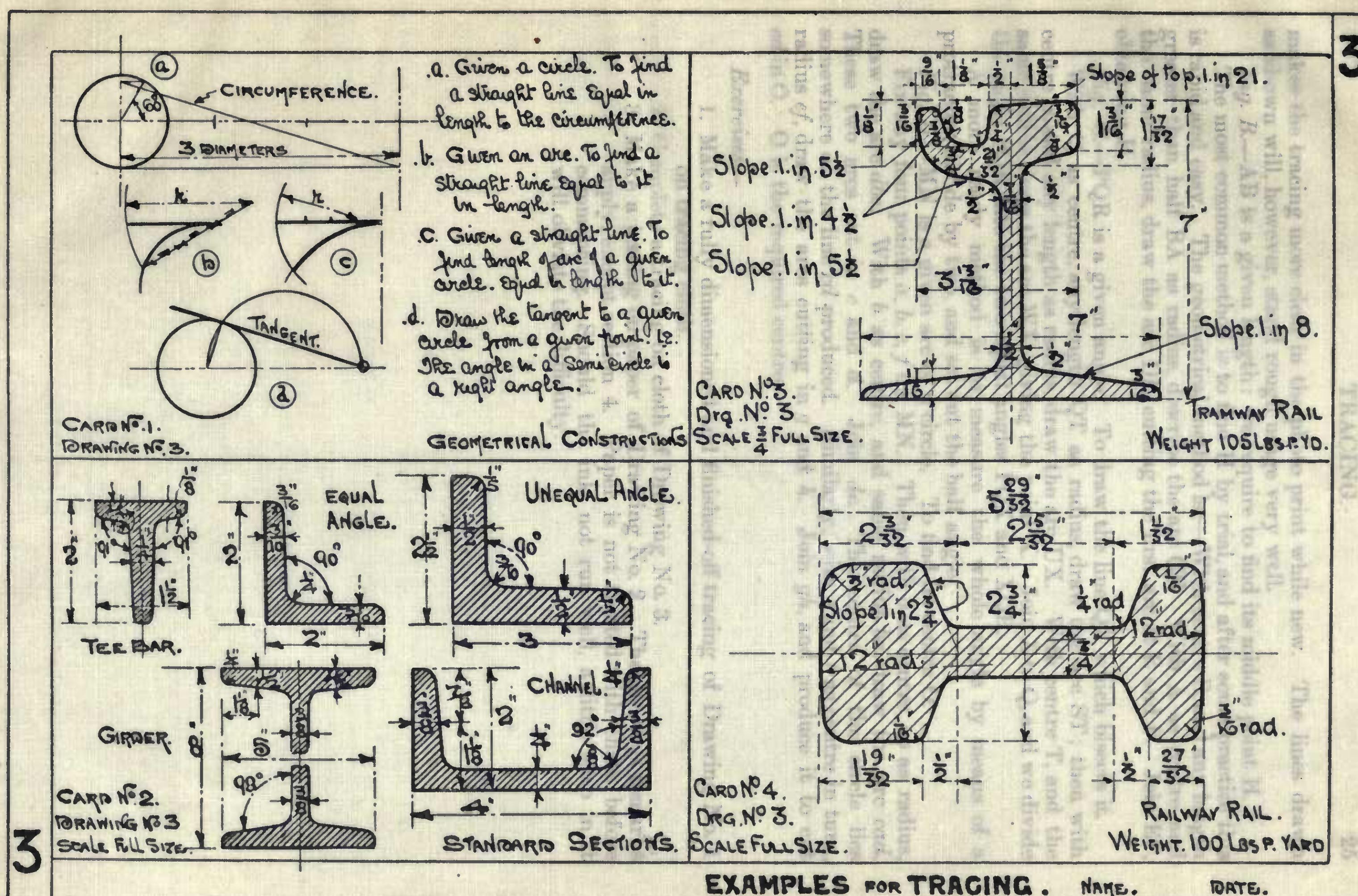


Fig. 6.—Tracing of Drawing No. 3.

globules, and does not leave the line with firm edges. This is due to the greasy surface of the cloth, to overcome which, rub the surface of the cloth with a duster and, preferably, powdered French chalk. In the absence of French chalk, ordinary chalk [illegible]

5. [illegible] tracing, be careful to see that it is dry before placing [illegible] set-square, or [illegible] it.
6. Draw [illegible] from left to right, [illegible] be careful that the drawing pen does not cut through the cloth.
7. It is usual to pen in all curves first, [illegible] it is so much easier to run a line [illegible] from a curve [illegible] a curve [illegible] straight [illegible].
8. If you are [illegible] to finish your tracing [illegible] do not pin in more curves than you can [illegible] and [illegible] the portion of the detail you are engaged [illegible] tracing cloth will expand and [illegible] during the night [illegible] if you fail to do this. Leave your tracing on [illegible] its appearance next class meeting.

Fig. 5.—[illegible] of lines required during tracing.

CENTRE LINE

[illegible] LINE

DIMENSION LINE

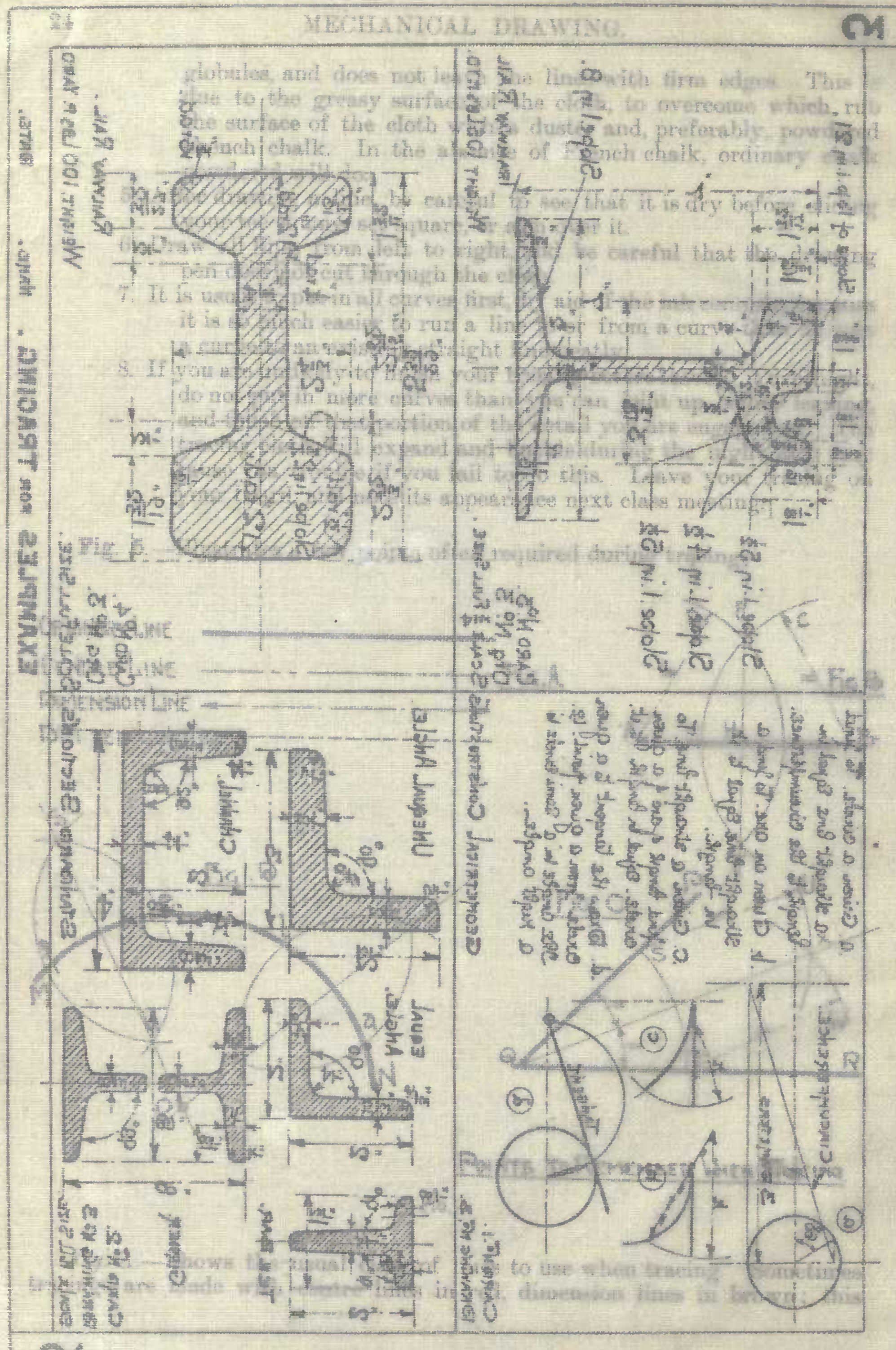


Fig. 5.—shows the usual kinds of lines to use when tracing. Sometimes tracings are made with centre lines in red, dimension lines in brown; this

makes the tracing more clear in the photo print while new. The lines drawn as shown will, however, stand rough usage very well.

Fig. B.—AB is a given length: we require to find its middle point H.

The most common method is to find H by trial, and after some practice this is rapid and easy. The geometrical method is:—With centre B, and any length greater than half BA as radius, describe the arc CF. With A as centre and the same radius, draw the arc DF, cutting the first arc at E and F. Join EF, obtaining H.

Fig. C.—PQR is a given angle. To draw the line QX which bisects it.

With Q as centre, any length QT as radius, draw the arc ST; then with centre S, and any length as radius, draw the arc UX. With centre T, and the same radius, draw the arc WX, giving the point X. Join X to Q, and we divide the angle PQR into the two equal angles PQX and XQR.

A more ready method is to measure the whole angle by means of a protractor, divide by two, and set out the half angle.

Fig. D.—MN is a given arc of a circle. To find its centre O.

Fix any four points *a*, *b*, *e*, *f* on MN. Then with *a* as centre, *ab* as radius, draw the arc *dbc*. With *b* as centre, and same radius *ba*, draw the arc *cad*. These two arcs cut in *c* and *d*. Join *dc*. The centre of the circle lies somewhere on the line *cd* produced. Similarly, with *e* and *f* as centre in turn, radius *ef*, draw the arcs cutting in *g* and *h*. Join *gh*, and produce it to cut *cd* in O. O is the required centre.

Exercises—

1. Make a fully dimensioned and finished-off tracing of Drawing No. 1 on tracing cloth.
2. Complete a tracing on cloth of Drawing No. 3.
3. Make a tracing on paper of Drawing No. 2. The previous remarks apply, except section 4. Paper is not treated with chalk before commencing. Should the ink not run well, a little soap in it will obviate the difficulty.

§ 3.—PHOTO COPIES OF TRACINGS.

THE tracing, complete and checked, becomes, as has been explained, the record. From it, by means of printing apparatus, as many copies as may be desired can be produced at quite a moderate expense. The tracing is carefully recorded by number, etc., in some form of index system, so that it can readily be found, and kept stored away, copies being taken from it as required.

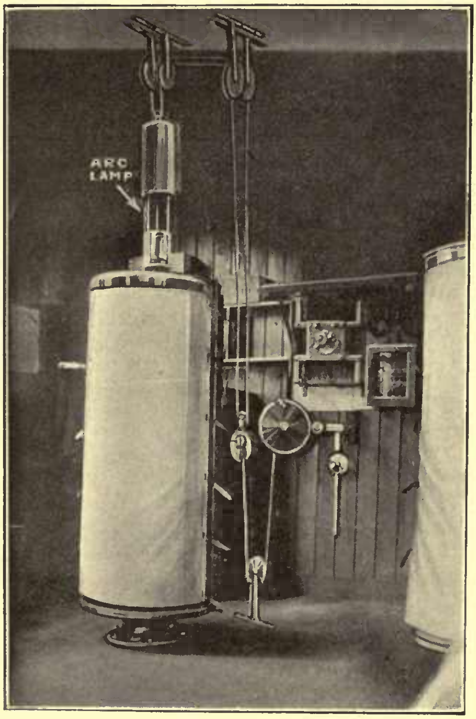


FIG. 7.—Photo Printing Apparatus.

For sending out when tendering for work, or for other special purposes, white prints, which can be coloured and finished off with any amount of ornamentation, are usually employed. For ordinary use, prints which will stand rough usage are preferred.

Printing Apparatus (fig. 7).—Where many tracings are produced, and a number of copies required from each tracing, the usual printing apparatus for rapid printing consists of a plate-glass cylinder 24 inches diameter by 54 inches high, open at both ends, and made up of two half-cylinders of $\frac{3}{16}$ inch thick glass mounted on a base-plate. The tracing to be copied is wrapped round the outside of the cylinder, then the sensitised or prepared paper is put round the tracing, and the whole strapped up tight by means of a canvas backing. An electric arc lamp without cover is suspended above the cylinder, by means of a regulating dashpot mechanism, and is arranged to descend at a slow and regular rate, down through the centre of the glass cylinder. The effect of the rays of light is to change the chemical composition of that portion of the sensitised paper not protected by the black lines on the tracing. The lamp is wound back to the top ready for the next

print, the canvas backing unstrapped, and the sensitised paper removed and thoroughly well washed in cold water and dried.

Fig. 8.—For practice in photo printing in connection with evening-class work, a flat sheet of plate-glass 24 inches by 18 inches by ¼ inch thick is mounted in a frame with a loose board at the back covered with ¼ inch thick felt, the board being arranged so that it can be wedged up tight against the glass face, so as to take all creases out of the tracing and so get the sensitised paper close up to the back of the tracing. As the size of the print being taken is not large (22 inches by 15 inches), the frame can be supported so as to stand vertically, and the cover removed from a convenient arc lamp, which is lowered and arranged to hang nicely in front of the frame. To obtain good prints, as regards time of exposure, is simply a matter of practice. Sunlight,

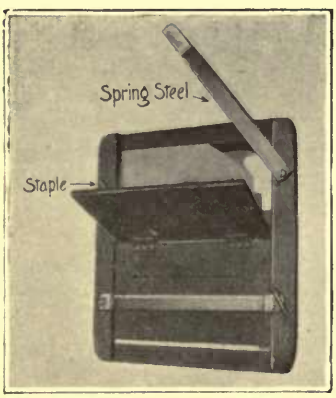


Fig. 8.—Photo Printing Frame.

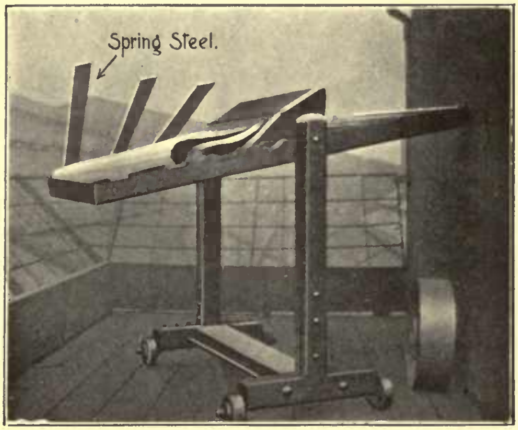


Fig. 9.—Photo Printing Frame.

when obtainable, will do just as well, and save the trouble of manipulating the arc lamp.

For taking large workshop prints by sunlight, an adjustable frame, with folding back-board and spring over each fold, is used, as shown in fig. 9.

Types of Prints.—The most usual print copies taken from tracings are:—

(*a*) White lines on a blue ground (ferro-prussiate paper, fig. 10).
(*b*) Black lines on a white ground (fig. 11).
(*c*) White lines on a brown ground.
(*d*) Blue lines on a white ground.
(*e*) Brown lines on a white ground.

For prints issued to the workshops, where they soon get dirty, more often than not quite carelessly, blue prints (white lines on blue ground) or brown prints (white lines on a brown ground) are mostly used.

White prints, or prints with a white ground, are usually reserved for special work. Shop prints of standardised work are usually mounted on cardboard sheets and varnished over with "paper varnish" to preserve them.

Instructions.—*When making a tracing which is to be used for photo-printing purposes, remember:—*

(*a*) The paper or cloth used should be very transparent, and of a white or bluish colour. If it has a yellow appearance good prints are impossible.
(*b*) All lines, figuring, and lettering should be bold and firmly drawn with good, thick, opaque ink. Stick ink, *i.e.* that rubbed down in a palette from a solid stick, is best, but is troublesome. Liquid ink of good quality is very convenient, and usually so satisfactory that it is practically always used.
(*c*) Centre lines should be drawn full red (vermilion), or black chain dotted lines thinner than the outline of the detail.
(*d*) Dimension lines should be drawn in full brown lines with burnt sienna, or black chain dotted lines, the dimensions and arrow-heads always being in black.
(*e*) The tracing should not be creased or folded in any way, but should be carefully rolled up. It should not be coloured at all. To show up parts for machining, take an ordinary writing pen, and with red ink (carmine) draw a good thick line along the surface to be machined, on the back of the tracing, blotting off the excess of ink.
(*f*) The tracing is not injured at all during the copying process, but care should be taken that it is not splashed with water, when washing the print.

Whenever it becomes necessary to make additions, or to write on a blue print, use the ordinary drawing instruments, or a writing pen and, as ink, a solution of common soda in water; also rub out with a blue pencil all the lines not required. To remove black lines from a white print, take a small camel-hair brush, and wash them over with a solution of oxalic acid in water.

Hectography (fig. 12).

It is often necessary to obtain a fair number of reproductions of small sketches, or written matter, and a ready method of obtaining these is to make use of a hectograph pad prepared as follows:—

Take 12 ozs. of glycerine, 3 ozs. of best glue, 3 ozs. of sugar, 12 ozs. of water

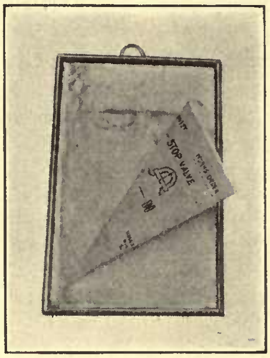


FIG. 12.—Hectographing Pad.

and ½ oz. of kaolin (china clay). Dissolve the glue in the water, add the other ingredients, thoroughly mixing up, and while warm pour into a shallow tin. These quantities are sufficient for a foolscap-size tin, 14 inches × 9 inches × ⅝ inch thick. Set aside the preparation on a level surface, in a place free

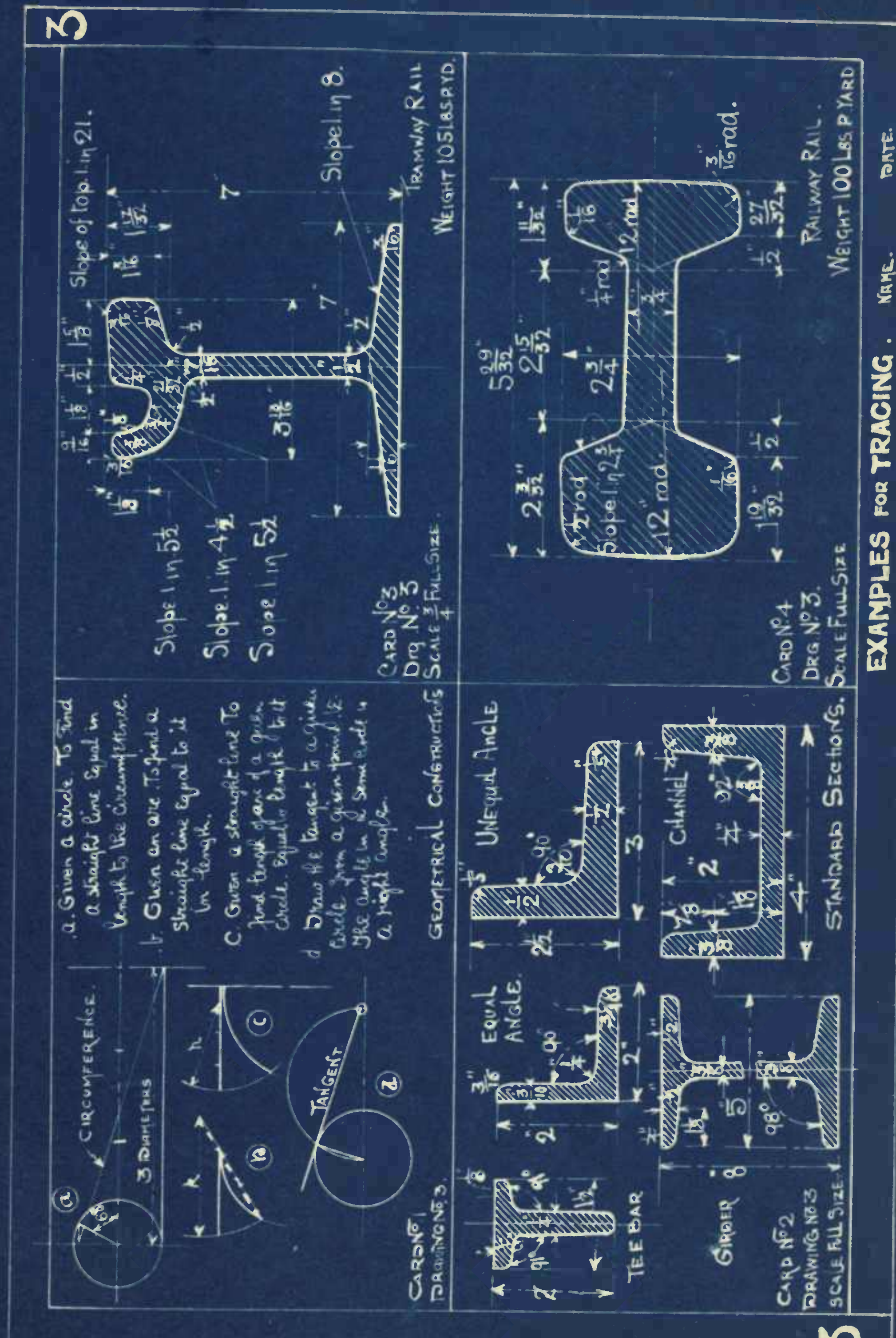
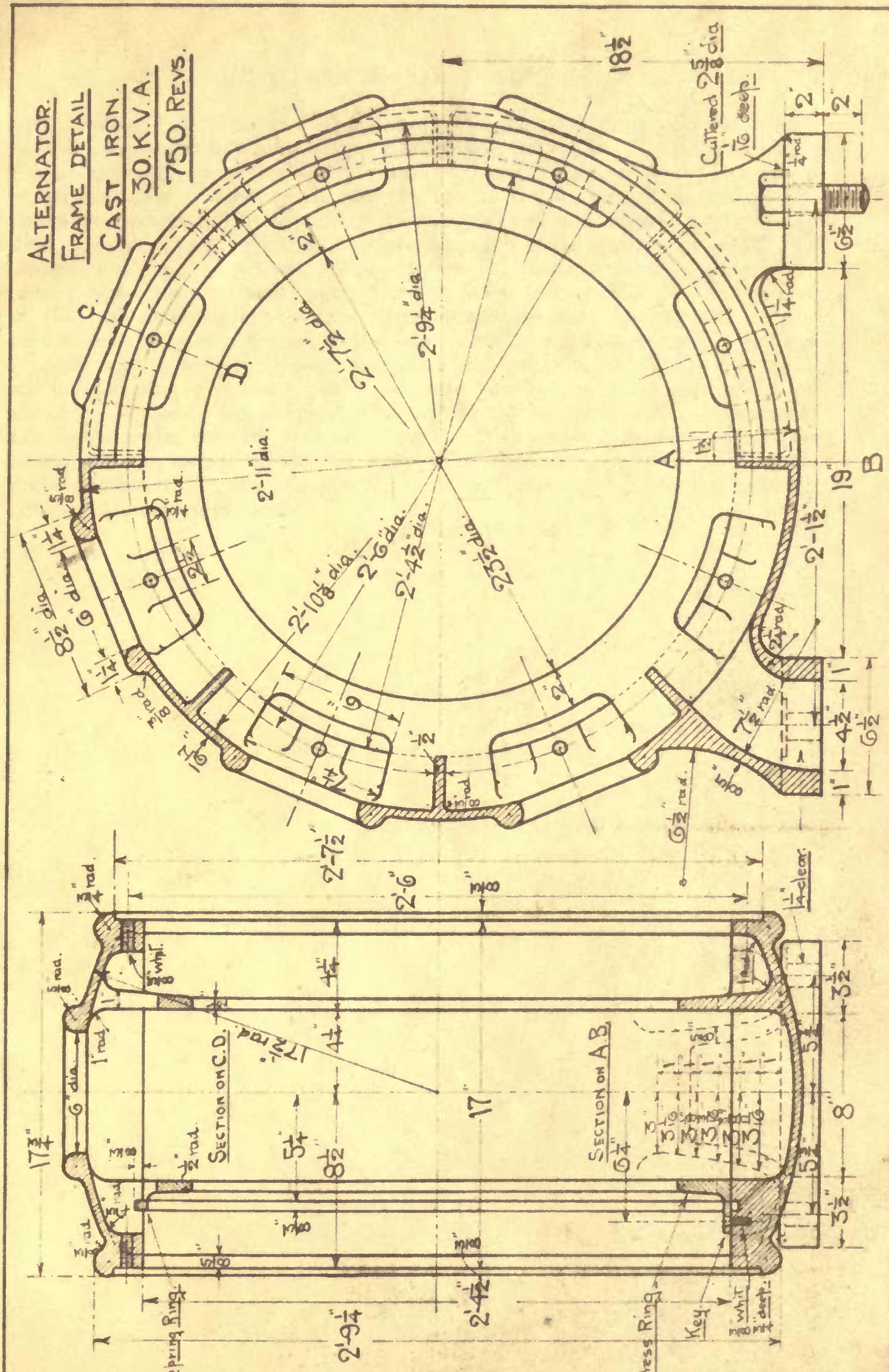


FIG 10 SPECIMEN BLUE PRINT.



— FIG. II. SPECIMEN WHITE PRINT. —

from dust, and allow to set. The drawing is made with a special ink, which is best purchased, but may be made, consisting of aniline blue, 1 oz.; water, 7 ozs.; spirits of wine, 1 oz.; glycerine, ¼ oz.; a few drops of ether, and a drop of carbolic acid. When ready, and the ink on the drawing has become dry, pass a wet sponge lightly over the surface of the pad, and allow it to get nearly dry. Lay the drawing on the surface, letting it remain in contact about one minute, applying slight but regular and equal pressure, then remove. To obtain copies, take a blank sheet of paper, lower it squarely on to the surface of the pad, avoiding air-bubbles, apply gentle pressure, and remove. Fifty copies can easily be obtained, if the right quality of paper is used. For the original copy a smooth, glossy, non-absorbent paper is best, while for copies an unsized and absorbent paper is more satisfactory than one with too smooth a surface. The original drawing should be made with a clean, new nib, as otherwise the ink will clog badly. If the pad is required again for immediate use, sponge off the ink still on the surface; otherwise, lay it aside, and the ink will be gradually absorbed into the material, and will not interfere with subsequent impressions.

§ 4.—PRINCIPLES OF PROJECTION.

WE have spoken of mechanical drawing as a language used by engineers, and of the necessity of making the drawing so that it may readily be understood. Unfortunately, we have in use several methods of projecting the different views of an object. At times most annoying mistakes occur, due to the misreading of the drawing. A man working in a shop with one system may come into another shop using another system, and for some time be fairly fogged, and not at all sure of his work. One sees holes and brackets handed due to the workman misreading two views of his drawing, and occasionally one meets a draughtsman using two systems of projection on the same drawing.

The object of this section is to place before the student the different methods in use, so that in any subsequent work he can decide what method of projection has been used, and also use the method he prefers. In the various examples which follow, the student will observe that method No. 1 has been mainly used, as it follows the ordinary teachings of geometry, and is probably the one most widely used in practice. The other methods, particularly No. 3, are worthy of attention.

Rectangular or Orthogonal Projection.

Fig. 13 is a picture view showing the projections of a standard brick, on the three plane surfaces X, Y, and Z, which are at right angles to each other, and to which reference will be made when explaining the following methods of projection.

Method 1.—Imagine the brick suspended in space, as shown in fig. 13, relative to the three planes X, Y, Z. Assume that you are looking down on top of the brick; you will see the top face marked B. An exact reproduction of what is seen is drawn on the plane X, lettered B_1, and is called the **plan.** Assume you are standing out in front of the brick; you see the face C. A drawing of what is seen is made on the plane Y, lettered C_1, and is called the **front elevation**. Assume you are looking at the side of the brick, seeing the face A. Make a drawing of what is seen on the plane or surface Z, letter it A_1, and call it the **side elevation.** So far we have dealt only with the picture view of fig. 13, where we have the three planes at right angles. To transfer this to our flat drawing board, imagine the plane X to turn down about OP as a hinge-line, until it lies flat with the plane Y, carrying the view B_1 with it. Imagine the plane Z to turn back about OQ as a hinge-line, until it also lies flat with the plane Y, carrying the view A_1 with it. We obtain a drawing as shown in fig. 14, in which—

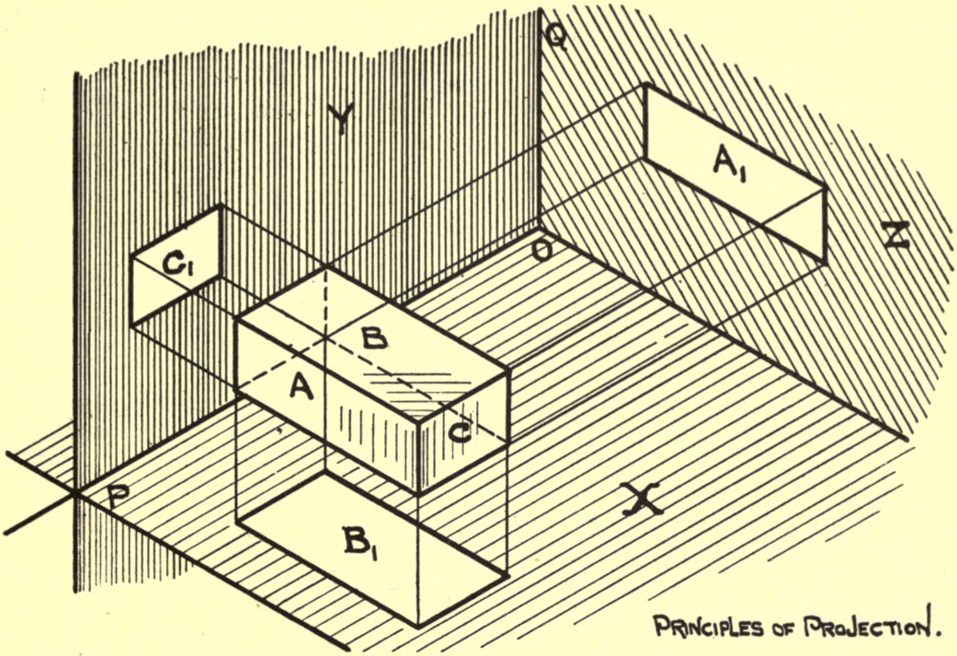

Q
Y
A1
Z
C1
O
B
A
C
P
X
B1
PRINCIPLES OF PROJECTION.

Fig. 13.

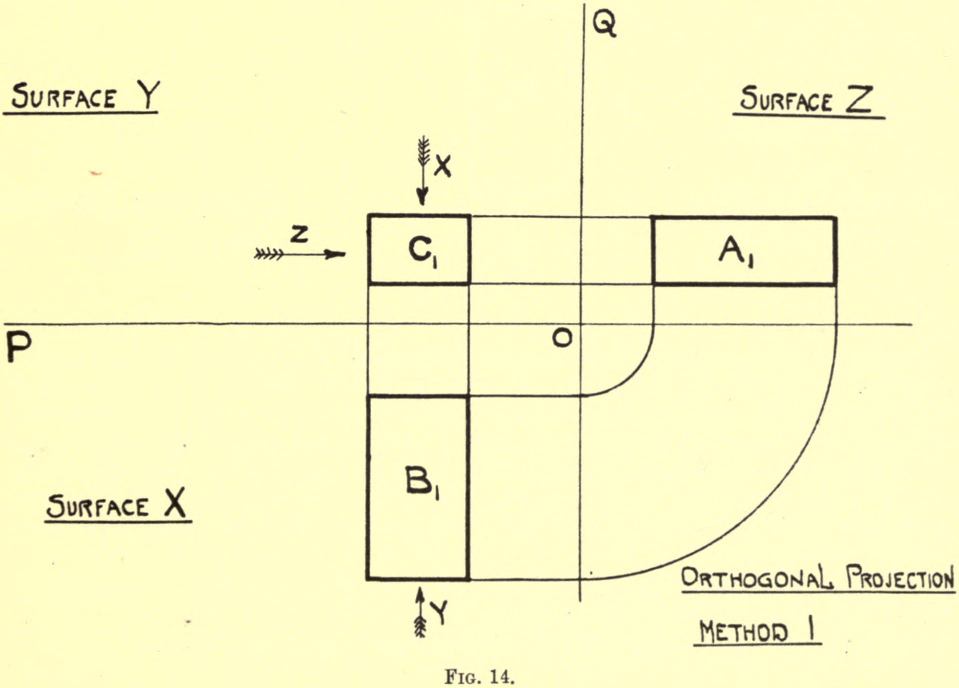

Q
SURFACE Y
SURFACE Z
X
Z
C1
A1
P
O
B1
SURFACE X
Y
ORTHOGONAL PROJECTION
METHOD I

Fig. 14.

C_1, the **front elevation**, is obtained by looking at the object in the direction of the arrow Y.
B_1, the **plan**, is obtained by looking in direction of arrow X.
A_1, the **side elevation**, is obtained by looking in direction of arrow Z.

In ordinary drawing the lines P, O, and Q and other construction lines are left off, and we simply have the views A_1, B_1, C_1 on the drawing, without any remarks as to what they are, or how they are obtained. This method of projection is spoken of as a clockwise, left-to-right, or a three-angle method of projection.

Method 2 (fig. 15).—This is a slight variation of method 1. The projection

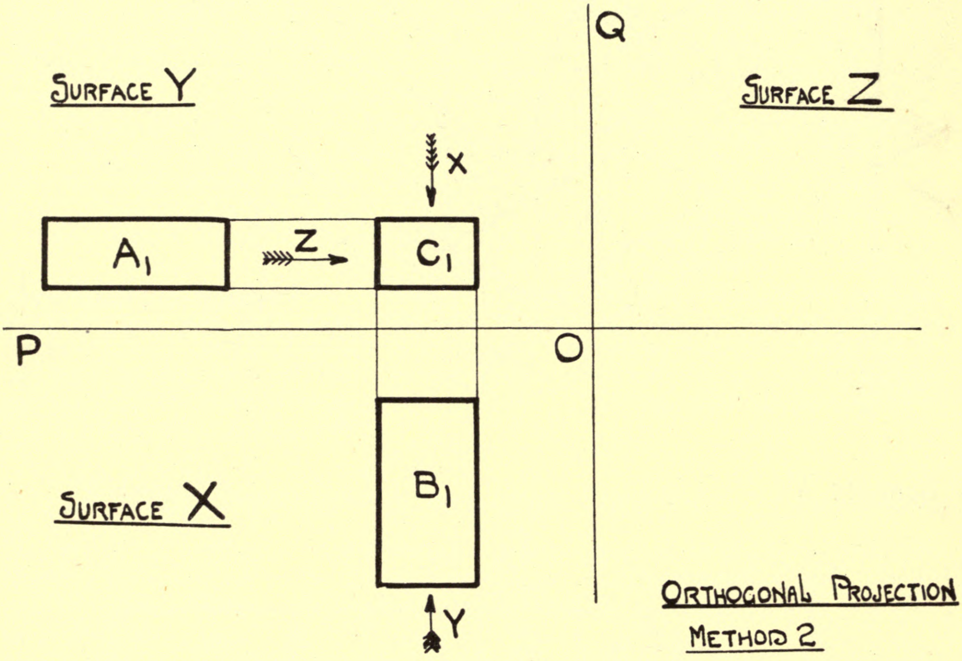


FIG. 15.

is made exactly as before described, but in representing this on the flat drawing board, the view A_1 is placed on the left-hand side of the view C_1, instead of on the right-hand side, as in method 1. For objects symmetrical about the centre line of view C_1 no difficulty arises, but for unsymmetrical objects the reading of the two views C_1, A_1 alone may cause serious blunders; and whenever there is any doubt, the third view, B_1, should be well studied, so as to find out the way in which the projection has been made. For this method we have in fig. 15—

C_1, the **front elevation**, obtained by looking in direction of arrow Y.
B_1, **plan**, by looking in direction of arrow X.
A_1, **side elevation**, obtained by looking in direction of arrow Z.

Method 3 (fig. 16) is another variation of method 1. The projection is made exactly as before, but in the flat representation the view A_1 is placed to the left of the view C_1, also the plan B_1 is placed above the front elevation C_1. Given three views, there can be no difficulty in making out the way in which the projection has been made; therefore, as in fig. 16, our object is represented by the views—

C_1, **front elevation**, looking in direction of arrow Y.
B_1, **plan**, looking in direction of arrow X.
A_1, **side elevation**, looking in direction of arrow Z.

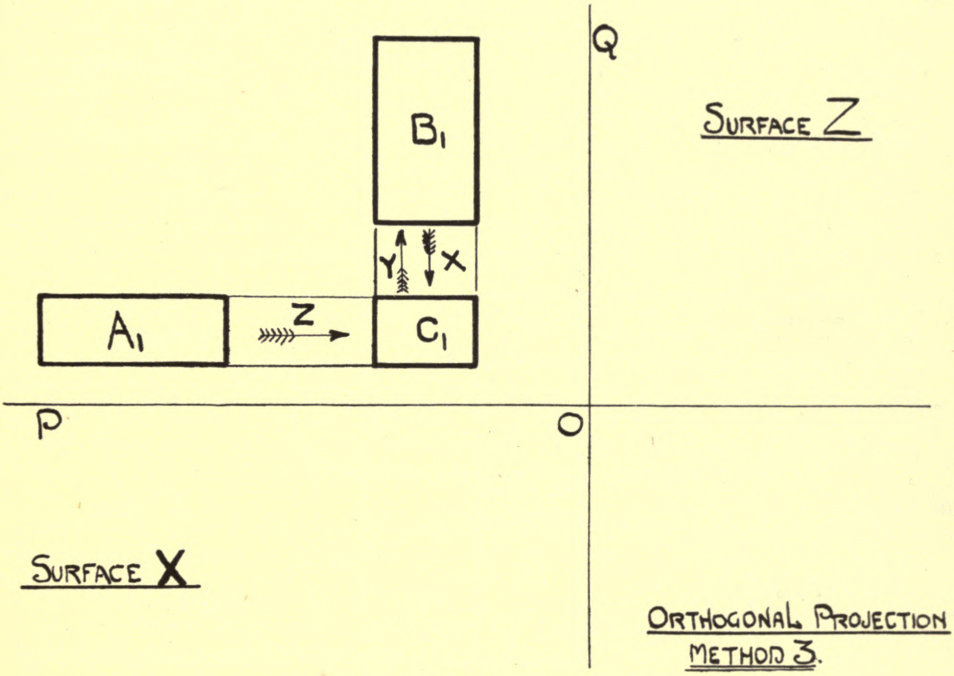


FIG. 16.

The advantages claimed for this method of projection are, the two elevations A_1 and C_1, which always contain the bulk of the work, are at the bottom of the drawing board, so that the general fatigue, due to bending over and stretching to the top of a large board, is somewhat avoided. While this is very desirable from a draughtsman's point of view, it leads to a method of projection not common, and the same comfort can readily be obtained by the wider use of adjustable boards and balanced tee squares.

With the general practice of representing simple objects by two elevations, the student should note that in all the three methods the same faces are represented. It is only the position of the views which has been altered. Failure to do this will result in methods 2 and 3 handing the detail. A reference to the third view will always straighten the matter out. This method of projection does not cause the same trouble to the workman as does method 2.

Fig. 17 shows the arrangement of the three methods relative to the common intersections OP, OQ of the three planes at right angles on which the projections are made.

These axes, meeting in O, divide the angle at O into four right angles, these being called respectively the 1st, 2nd, 3rd, and 4th angles, as is usual in geometry. We may speak of and distinguish the three methods of projection as follows:—

Method 1, three-angle projection, *i.e.* views are drawn in three of the angles

Method 2, two-angle projection.

Method 3, one-angle projection.

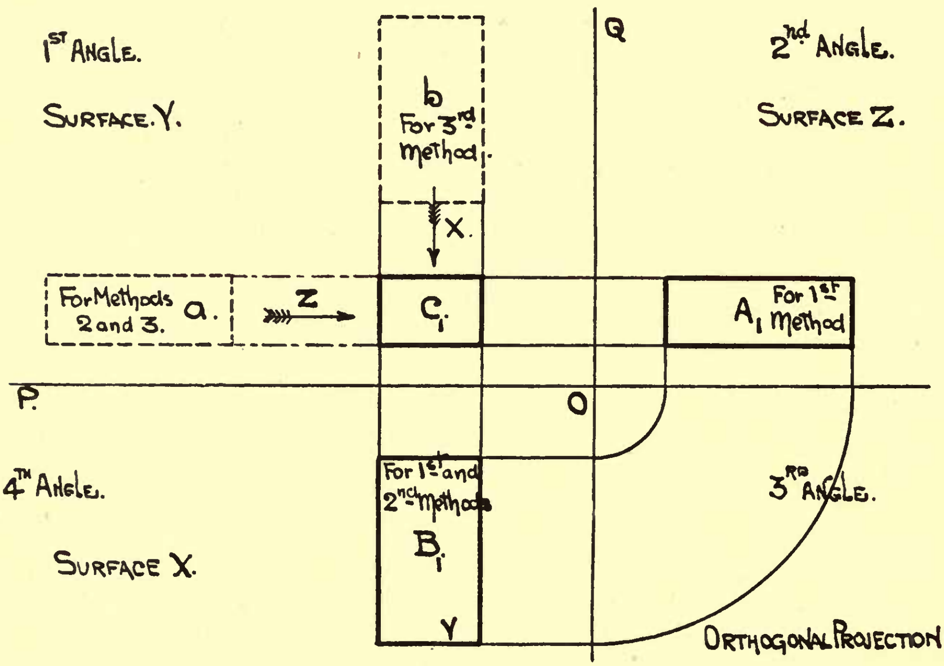


FIG. 17.

Method No. 4.—Refer to fig. 13. In the three methods of projection just described, whichever way we have arranged the views or projections, we have always represented the same three faces, A, B, and C, of the brick. The method we now consider results in quite a different set of faces being seen. In fig. 13, imagine the brick suspended as before in space relative to the three surfaces X, Y, and Z. Assume that these surfaces or planes are made of mirror-glass. The drawing is made to represent exactly the images seen in these surfaces. Thus, on the surface Y, instead of representing the face C, we represent the parallel opposite face, which lies nearest the plane. On the surface X we represent the parallel opposite face to the face B; and similarly on surface Z we have the parallel opposite face to A. On the flat developed representation (refer to fig. 17) we have three views occupying the positions

C_1, B_1, and A_1, called front elevation, plan, and side elevation, exactly as in method 1; but it must be carefully remembered it is the detail of the parallel opposite faces to C, B, and A which is represented.

Isometric Projection.

In this method the detail under consideration is represented by a single view, drawn in such a way that all dimensions of length, breadth, and thickness are readily shown. The great advantage is that a pictorial representation of the detail is obtained, which enables its exact shape or form to be more readily grasped. The disadvantage and objection to the system are the time and labour necessary to produce a satisfactory representation of complicated details. For simple details required in a hurry, or to be produced by a handy man, or even by a skilled man, there is nothing to compare with this method; whilst, for the workman to give expression to his ideas and opinions, it will be found much more simple than the use of three views. Referring to fig. 13, page 31, representing the brick used to explain the other methods of projection, the picture view with faces marked A, B, C is really an isometric projection of a standard brick, and would be a complete representation if the dimensions of length, breadth, and depth were added.

Metric Projection.

In making an isometric projection all lines have to be drawn with the 60° set square. This requires a considerable amount of changing about of the square. A modification is to make one set of lines horizontal, enabling the tee square to be used, the other set being drawn by the set square. This method is mainly used for the making of rough drawings of simple details.

Exercises.—Represent in rectangular projection (in each case by three views), also in isometric projection—

- A cube length of edge 2 inches.
- A square slab 3 inches by 3 inches by 1 inch thick, with a 1 inch square hole through the centre.
- A circular slab 2 inches diameter by 1 inch thick. Refer drawing No. 4A.
- A bolt head and shank—head 2 inches square by ½ inch thick, shank 1 inch diameter by 4 inches long.

EXAMPLES ON RECTANGULAR PROJECTION.

Drawing No. 4.

Card No. 1. Parallel Packing (fig. 18).—Many details which require machining are of such a shape that they cannot be readily cramped down to the machine bed, so as to lie rigid and steady. A packing piece put between the machine bed and some flat surface on the detail enables it to be bolted down firmly, without warping, or danger of it springing during or after the machining process. The packing shown is of cast-iron, machined true, and square on all the outside faces.

Draw the three views shown. Scale, half full size.

Example.—Estimate the volume of material in the packing, and its weight, given 1 cubic inch of cast-iron weighs 0·26 lb. An actual block from the above drawing weighs 29½ lbs.

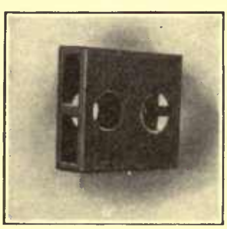


Fig. 18.—Parallel Packing Block.

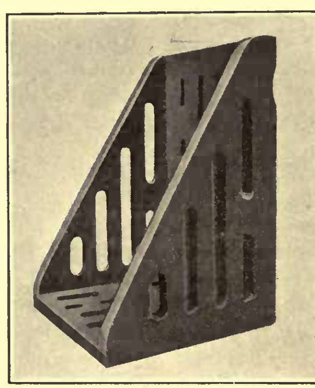
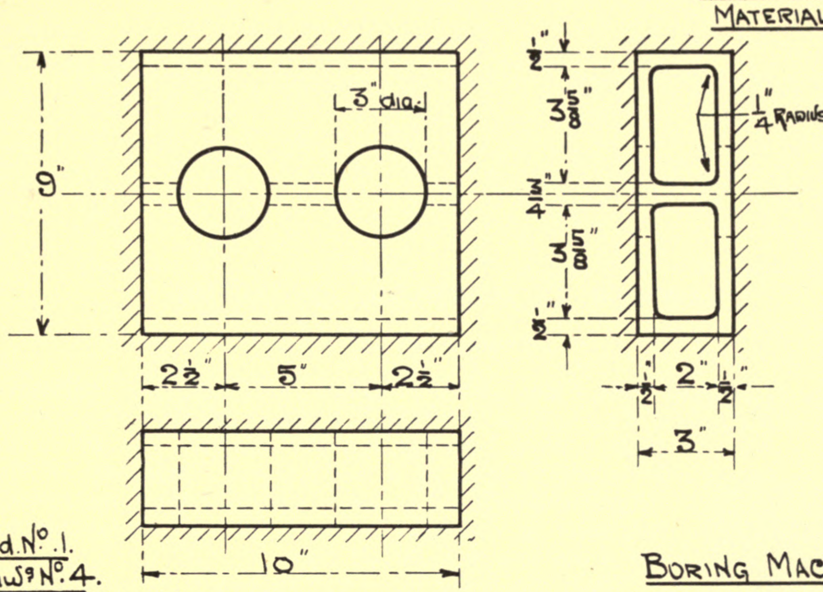


Fig. 19.—Angle Bracket.

Card No. 2. Angle Bracket (fig. 19).—In the machining (such as drilling, tapping, boring, and facing) of many details, it is not possible conveniently to bolt them to the bed of the machine, in which case an angle bracket, made of cast-iron, machined true all over the outside faces, can, by means of the large number of slot-holes in it, be securely and rigidly bolted to the machine bed, and the detail in hand bolted up to it, in the position most convenient for the machining operation to be carried out.

Draw the three views shown to a scale of quarter full size. Estimate the volume, and hence the weight, of the angle bracket. The actual bracket weighs 101 lbs., machined and finished off.

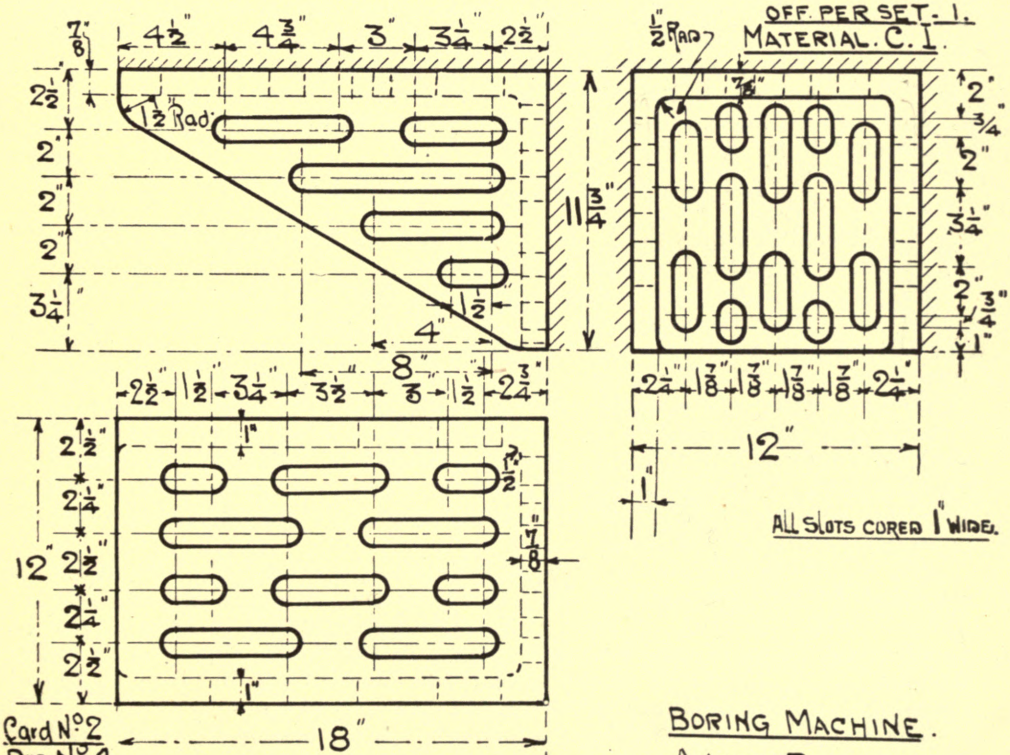
OFF PER SET. 3.
MATERIAL. C. I



Card. No. 1.
Drawg. No. 4.
Scale Half Full Size.

BORING MACHINE.
PARALLEL PACKING.

OFF. PER SET. 1.
MATERIAL. C. I.



ALL SLOTS CORED 1" WIDE.

Card No. 2
Drg. No. 4
Scale - 1/4 - Full size

BORING MACHINE.
ANGLE BRACKET.

EXAMPLES ON ISOMETRIC PROJECTION.

Drawing No. 4A.

Card No. 1. Magnet Pole Piece.—This is shown in rectangular projection, method 1. It consists of two pieces of soft iron, sweated to two side-pieces of brass, with a hole through the middle. The whole fits between the jaws of a magnet, and forms part of the magnetic circuit of an electrical measuring instrument (ammeter or voltmeter), as used for continuous current. Set it out to a scale of full size.

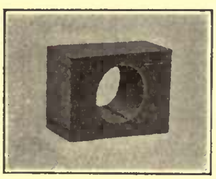


FIG. 20.—Magnet Pole Piece.

Card No. 2 (fig. *b*).—Draw an isometric projection of the detail Card No. 1.

From a point O draw the three axes OP, OQ, OR equally inclined to each other, that is, each making an angle of 120° with the other two. Take this point to correspond to the point A, the axis OP to the line or edge AB, the axis OQ to the line AC, and OR to AD.

Note.—In making an isometric drawing in practical geometry an isometric scale is used, thus:

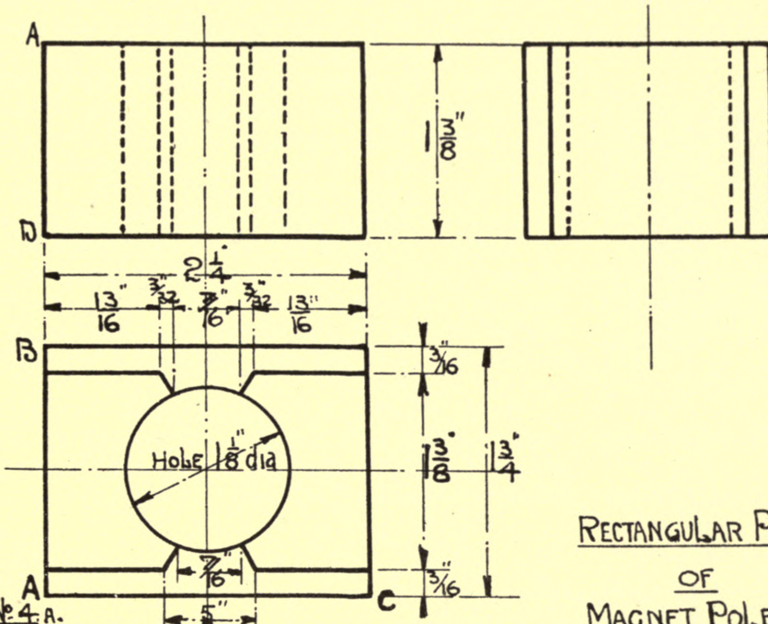
$$\text{Isometric length} = (\sqrt{2} \div \sqrt{3}) \times \text{true length}.$$

For mechanical drawing this is not taken into account, and actual lengths are measured off on the isometric representation.

Fig. a.—Shows how the isometric projection of a circle on a square surface is obtained. Draw the diagonals AD, BC of the square, also the horizontal and vertical diameters. Through the points where these lines cut the circle, draw lines parallel to AB and AC. For the isometric projection draw the lines *ab*, *ac* from any point *a*, each inclined at 30° to the horizontal. Make *ab* equal to AB and *ac* equal to AC, and complete the figure *a b c d*. Along *a c* mark off lengths *a*, 0, 1, 2, 3, 4, *c*, exactly equal to A, 0, 1, 2, 3, 4, C, and draw parallels to *ab*. Similarly, along *ab* mark off corresponding lengths from AB and draw parallels to AC. The intersections give eight points, joining which gives the isometric of the circle.

Fig. b.—Along the axis OQ mark off a length equal to AC, Card No. 1, and along axis OP a length equal to AB. Complete the outline of the top face. Along the axis OR mark off from O a length equal to AD in Card 1, and complete the outline of the lower face. Draw in the vertical lines, obtaining the isometric of the outline of the block. The isometric of the hole on the top face can now be obtained by the method described in fig. *a*.

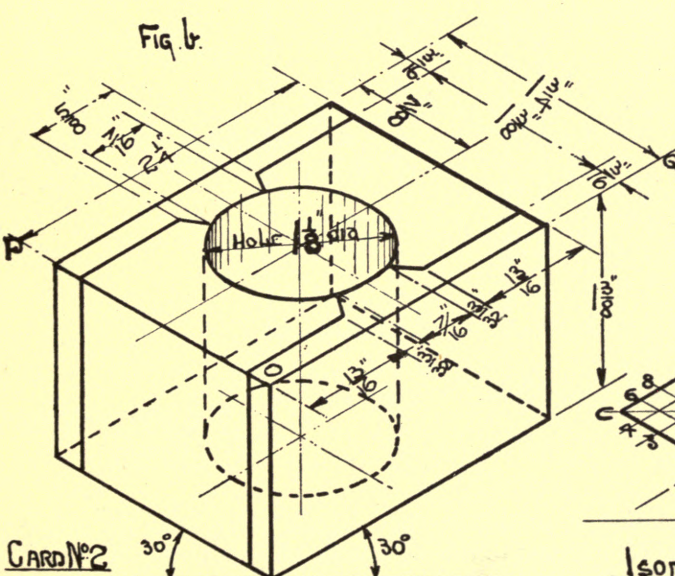
The dotted circle representing the hole through the bottom face is an exact



Card No 1.
Drawing No 4 A.
Scale Full Size

RECTANGULAR PROJECTION
OF
MAGNET POLE PIECE.

Fig. b.



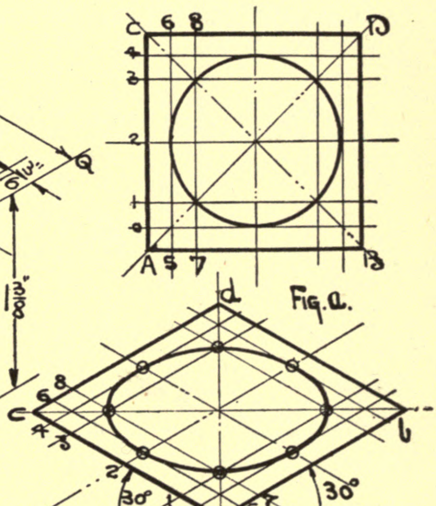


Fig. a.

Card No 2
Drawing No 4 A
Scale Full Size

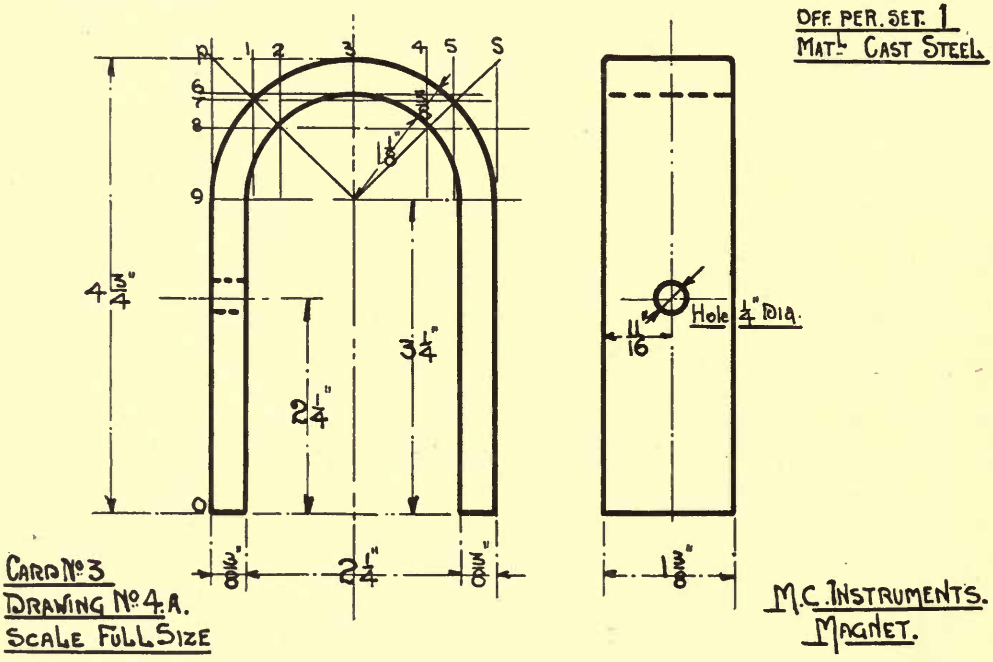
ISOMETRIC PROJECTION
OF
MAGNET POLE PIECE

duplicate of that for the top face, every point on it being $1\frac{3}{8}$ inches below the corresponding point on the top circle, so that by dropping perpendiculars from the top circle, each $1\frac{3}{8}$ inches long, it is readily obtained. To obtain the lines showing the division between the brass and iron pieces, along OP measure off corresponding lengths from AB, and draw parallels to OQ. Along OQ mark off corresponding lengths from AC. Draw lines parallel to OP. The intersections enable the detail to be filled in as required.

FIG. 21.—Permanent Magnet.

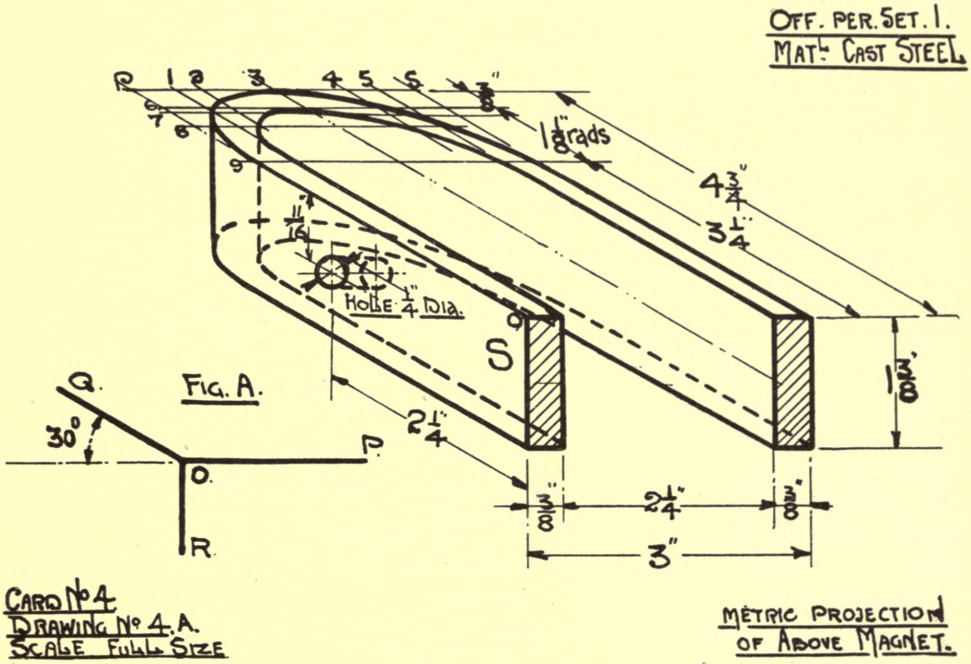
In this method of projection, no attempt is usually made to show too much detail, by putting in dotted lines to represent all the hidden edges, as thereby the production of the drawing is hastened, it is not so confused, and yet may contain all necessary data and information.

Card No. 3.—The magnet used in connection with the previous detail is shown in rectangular projection, the method of fixing the block in the magnet being omitted. Set out to a scale of full size.



Card No. 4.—Draw in metric projection the magnet given. To do this, take three axes, OP, OQ, OR, inclined to each other as shown in fig. A, and in which OP and all lines parallel to it are drawn by the tee square, the set square being used for OR and OQ and all lines parallel to them. This method of projection is mainly used for making a rough hand-sketch of simple details.

The method of obtaining the projection of the semicircular end is indicated by Cards Nos. 3 and 4, and will not offer much difficulty. The dotted lines representing hidden edges may with advantage be omitted, or may be obtained by simply dropping perpendiculars from the top face.



Before commencing the drawing, observe that it will be advantageous to divide the working area into four equal cards, so as to obtain a neat arrangement of the details.

BALANCED BALL HANDLE.

Drawing No. 5.

Card No. 1.—During a machining process, when the tool is cutting, there is always an amount of vibration and jar, which depends upon the depth of cut and the amount of support given to the material being acted upon. To vary the cut, the tool is carried in a slide, and adjusted by a screw, which is turned by a handle or wheel of some kind. If this handle is not balanced about the axis of the screw, the jar will cause it to turn, until the heaviest part is vertically beneath the axis of the screw. Thus, if left with the heavy unbalanced part near the top, it would gradually work down to the bottom, and vary the cut unknown to the operator.

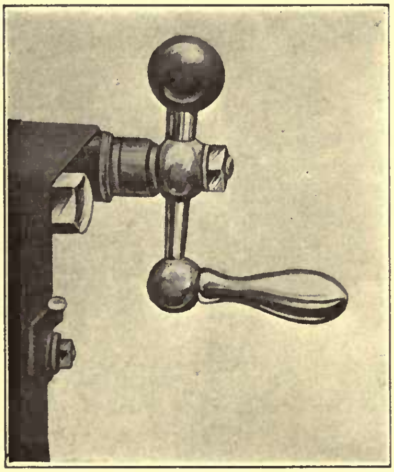


FIG. 22.—Balanced Ball Handle.

Draw full size the two views shown, and add a plan.

Example.—To show that the handle is balanced about the centre line CL, neglect the centre boss, as it is symmetrical about CL. By definition, force is that which tends to produce an effect. The moment of a force is the tendency of the force to produce rotation about a point, measured by the product of the force and the perpendicular distance from the point to the line of action of the force. If a body is in equilibrium, the moments tending to turn it in one direction are balanced by the moments tending to turn it in the opposite direction.

Volume of a sphere $= \frac{4}{3} \times \pi \times \text{radius}^3$. Weight of 1 cubic inch of mild steel $= {\cdot}28$ lb. Dividing the detail up into elements, and taking moments, we have :—

Weight of ball end	= ·625 lb.	Moment = 1·49 inch-lbs.	
„ plain part	= ·124 „	„ = ·136 „	Total, 1·626 inch-lbs.
„ handle	= ·385 „	„ = ·96 „	
„ handle ball	= ·17 „	„ = ·425 „	
„ plain part	= ·12 „	„ = ·17 „	Total, 1·555 inch-lbs.

The difference is just over 4 per cent., which may be neglected. The detail as above actually weighs 1 lb. 11 ozs., including, of course, the centre boss.

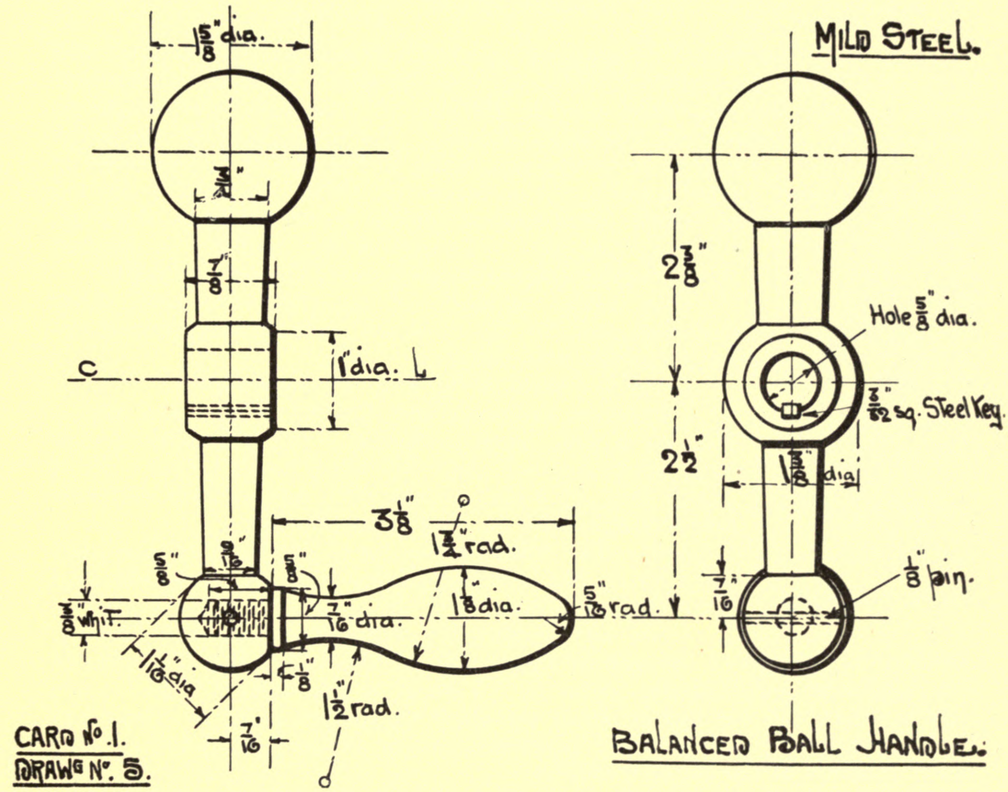
Example.—Set out a balanced ball handle similar to Card No. 1, but to the following dimensions. (Make a calculation as above to see if it is balanced.)

Centre boss $1\frac{1}{2}$ inches diameter, 1 inch across flat faces. Hole and key as in Card No. 1.

Ball end $1\frac{3}{4}$ inches diameter; centre $4\frac{1}{8}$ inches from CL. Plain part $\frac{15}{16}$ inch down to $\frac{11}{16}$ inch.

Handle ball $1\frac{1}{4}$ inches diameter; centre $4\frac{3}{8}$ inches from CL.

Handle $1\frac{1}{4}$ inches diameter, 4 inches long, $\frac{1}{2}$ inch screwed end.



Note.—The drawing should be arranged for two cards, each $10\frac{1}{2}$ inches by 14 inches. Card No. 1 is then to be set out in one section, followed by the example and the calculation in the other section.

LATHE CARRIER.

Drawing No. 6.

TAKE the simplest case of a mandrel supported between the lathe centres, and carrying a detail the surface of which requires turning. To drive the mandrel round against the resistance due to cutting, a connection must be made between the mandrel and the lathe spindle. The face-plate of the lathe carries a driving-pin, while on the end of the mandrel is fixed a lathe dog or carrier (as shown in fig. 23), the leg of which bears against and is driven round by the face-plate driving-pin. The end of the mandrel is clamped in the dog by the hardened point of the screw shown.

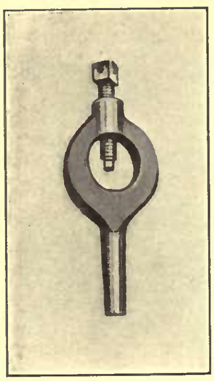


FIG. 23.—Lathe Dog.

This carrier is made of malleable cast-iron, other materials used for the construction being mild steel drop-forgings, also steel castings.

Draw to a scale of full size the views shown.

For future reference, the details of the screw are:—Mild steel with hardened point $\frac{1}{2}$ inch diameter, $\frac{5}{8}$ inch long, screwed $\frac{5}{8}$ inch diameter Whit. for $2\frac{1}{2}$ inches. Head $\frac{3}{4}$ inch long by $\frac{3}{4}$ inch square, with one $\frac{9}{32}$ inch diameter hole through it for turning or tommy bar.

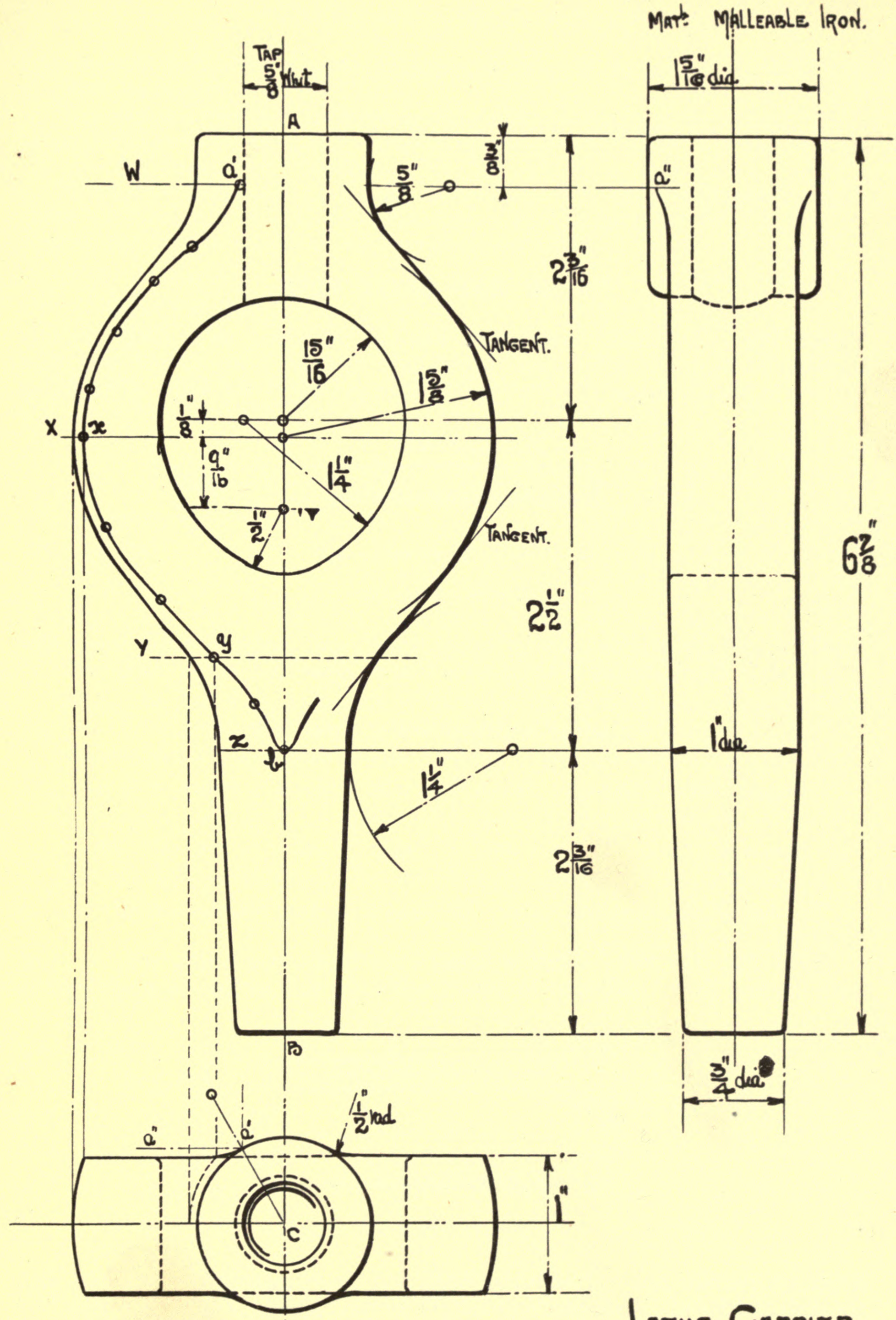
Note.—The form of the curve produced on the front elevation by the rounding of the edges should be obtained correctly as follows:—

Take any section as represented by the line X. Assume the outline of the carrier rotated about the axis AB. The plan of this section is a full circle, centre C. A strip of this section 1 inch wide only is used. On the face or front elevation we get the point x. Similarly for the section Y and as many other sections as taken. To determine the limiting points of the curve, a and b:—

(b) Take the section Z, where the diameter of the section is the same as the width used in plan. The circle just touches the flat side, and we get the point b on the vertical centre line.

(a) The boss, which is tapped for the clamping screw, curves into the flat sides as shown in plan. Take sections as before. Where the circle in plan cuts the outline of the detail, projected upwards, will be found the point on the curve. Take the section W containing the circle at which the screw boss begins to spread out. The boss radius on to the flat side leaves this circle at a' in plan, which determines a' and a'' in elevation.

The curve should be completed on the right-hand half of the **front elevation.** It has been omitted so that the construction of the outline will be more clearly indicated.



LATHE CARRIER.

TO TAKE UP TO 1 7/8" DIA. BARS

DRAWING No. 6.

SCALE FULL SIZE

TAPER AND SPLIT PINS.

Taper Pin (fig. 24).—A convenient method of fixing two details rigidly together is to make a common taper hole through both details, and then drive in a pin, the taper of which is the same as that of the hole. The fixing

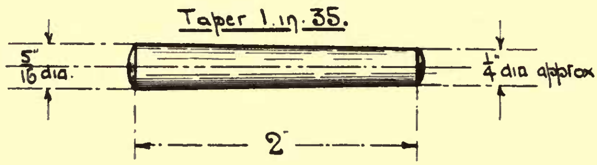


FIG. 24.—Taper Pin.

is secure, and the details may be taken apart, and replaced with ease. The size (that is, the diameter of the pin) is always measured at the thick end.

Taper of English Standard Taper Pins.

Length in Inches	Up to 1½.	1⅝ to 2.	2¼ to 2½.	2⅝ to 3.	3¼ to 4.	4⅛ to 5.
Taper, 1 in . .	30	35	40	45	50	55

The standard American taper for pins and for reamers of all sizes is 1 in 48.

Split Pin (fig. 25).—When a detail runs loose on a shaft, pin, or stud, without any great tendency to travel endways, end motion is prevented by

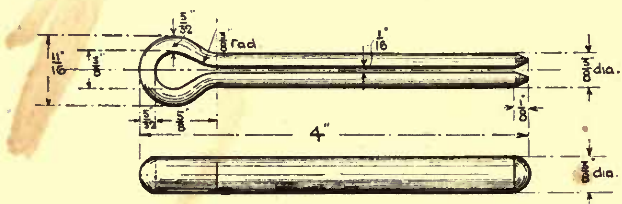


FIG. 25.—Split Pin.

drilling a parallel hole through the shaft, and inserting a split cotter pin with the end opened out. This prevents the pin dropping out. The "cotter pins" (as

they are called) are made slightly under size, so as to fit into holes drilled of standard diameters.

Example.—Describe the process of making a taper hole, suitable for a taper pin, through a boss, and the shaft on which it is to be so fixed, so that the two will turn rigidly together.

Example.—The student should, from his own notes and observations, make out a table, of which the following is an example, carefully noting the class of work from which the observations are taken.

Diameter of shaft in inches . . .	$\frac{3}{8}$ to $\frac{9}{16}$.	$\frac{5}{8}$ to $1\frac{1}{8}$.	$1\frac{1}{4}$ to $1\frac{3}{4}$.	2 to 3.	$3\frac{1}{4}$ to $4\frac{1}{2}$.
Diameter of split or taper pin in inches .	$\frac{1}{8}$	$\frac{3}{16}$	$\frac{1}{4}$	$\frac{3}{8}$	$\frac{1}{2}$

Taper Diameters.

Taper per foot .	$\frac{1}{8}$	$\frac{1}{4}$	$\frac{3}{8}$	$\frac{1}{2}$	$\frac{3}{4}$	1	$1\frac{1}{2}$	2	$2\frac{1}{2}$	3 inches.
Included angle .	0 36	1 12	1 47	2 23	3 35	4 46	7 09	9 31	11 54	14 15 degrees and minutes.

Taper per foot is the reduction in diameter per foot length. The included angle is the angle at the vertex of the cone formed by the taper.

The angle with the centre line is half the included angle.

SECTIONS.

Use of Sections.—In making a drawing, lines which represent edges hidden from view by portions of the detail in front of them are drawn dotted. In most cases this does not show with sufficient clearness the internal arrangement of the detail. We then assume the detail cut into pieces along imaginary surfaces, and, just as before, draw the projection of the part which would remain if one or more of the pieces cut off by the imaginary surfaces (called *section planes*, the end view of these planes being called the *lines of section*) were removed out of the way.

Sections.—Whenever we draw a sectional representation, we assume the surface or cutting plane actually to cut through the material, and that a part or parts are removed. In the drawn projection the most important lines are those actually on the cutting surface. To show up clearly the shape of the detail on the cutting plane, that is, the actual material which would have to be cut through to part the solid object along this plane, various methods are used.

Section Lines (fig. 26).—Using special forms to denote different materials, the types of line used to represent the materials in most common use are as shown. In section lining a drawing the following points should be noted:—

1. All section lines should be drawn in with the 45° set square, except where three or more different pieces meet, when the lines must be arranged to show each separate part up in the clearest possible way.
2. Lines representing the section of the same piece should all run in the same direction.
3. Where two pieces abut on each other, to draw the section lines for the second piece turn the square over—that is, the second set of lines will be at right angles to the first set.
4. Do not crowd the section lines too close together, and do not draw them to run through or over dimension lines or dimensions.

This method has but a limited application, the main objections being:—

1. A lot of time can be wasted drawing in the fancy and broken lines.
2. Except for the common materials, there is no uniformity in the character of the lines used by different people.

Colouring.—It sometimes happens that we require to finish off a drawing, tracing, or white print, in which case the list of water-colours given enables the different materials used in the construction to be readily picked out. Use moderately dark tints for sections, and light washes for flat surfaces. For sections

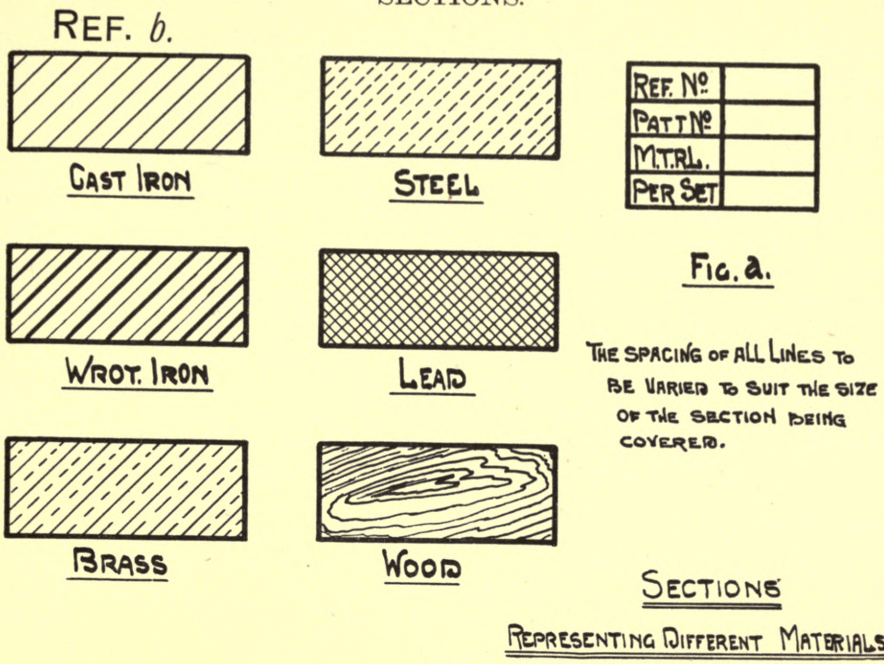


FIG. 26.

CAST IRON	PAYNES GREY DARK FOR SECTIONS --LIGHT FOR FLAT SURFACES
WROT IRON	PRUSSIAN BLUE
STEEL	PURPLE CRIMSON LAKE & PRUSSIAN BLUE
MALLEABLE IRON ...	GREEN GAMBOGE & PRUSSIAN BLUE
COPPER	CRIMSON LAKE WITH EQUAL PARTS OF BURNT SIENNA
GUN METAL	GAMBOGE WITH A LITTLE CRIMSON LAKE
BRASS	YELLOW IE. GAMBOGE
TIMBER	BURNT SIENNA - LIGHT. DARK for GRAINING
LEAD	DILUTE INK
INSULATING MATERIAL ..	LIGHT BROWN
STONE	GAMBOGE DARKENED WITH INDIAN INK.

COLORS USED ON A DRAWING REPRESENTING DIFFERENT MATERIALS

it is sometimes useful to put in section lines before colouring. To colour a drawing satisfactorily is a matter of some practice. In ordinary engineering work, the colouring of prints and tracings is limited entirely to drawings accompanying tenders or estimates.

Section Lines.—The most common and best method is to use a uniform set of lines to denote all sections (refer to *b*, fig. 26), and to stamp beside each detail a table of information as per fig. *a*, fig. 26, in which are written particulars by means of which the detail is identified, as well as the material of which it is to be made. There can then be no mistake due to the misunderstanding of conventional lines. Instead of the table of information just mentioned, it is sometimes usual to give a detail a reference number only, as 6, that is, a number enclosed in a circle to distinguish it, and to make a table down the right-hand side of the drawing, giving reference number, name of detail, material, pattern number, off per set, etc. This is by far the best method. Often this table is not put on the drawing, but made up in the form of a standard requisition sheet, used in conjunction with the drawing.

VEE BLOCK.

Drawing No. 7.

To pack and securely hold a round detail, to prevent it rolling or sliding under the action of the tool during machining, is somewhat difficult. A vee block (fig. 27) helps considerably, and is useful in setting out work, drilling holes in studs and round work generally. For heavy work, the job is laid on two or more blocks; then clamps, one end resting on the job, the other on packing placed on the machine bed, hold it down firmly by screwing up the intermediate bolt.

Draw to scale of full size the views indicated.

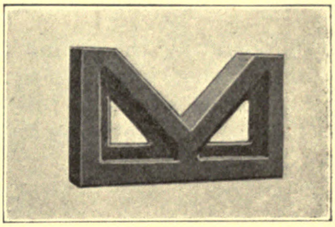
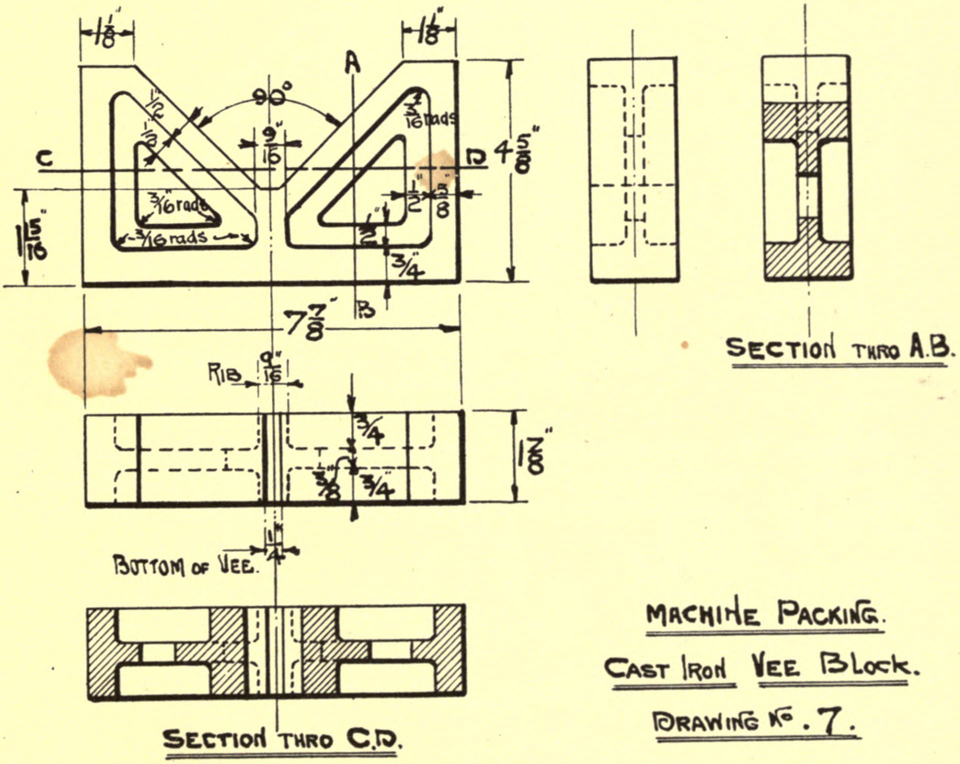


FIG. 27.—Vee Packing Block.



REGULATING HAND WHEEL.

Drawing No. 8.

For operating the sliding tables of machine tools, and similar uses, the form of hand wheel shown in fig. 28 offers a very comfortable and ready grip.

Draw to a scale of full size the views shown.

Add a side elevation looking in the direction of the arrow A.

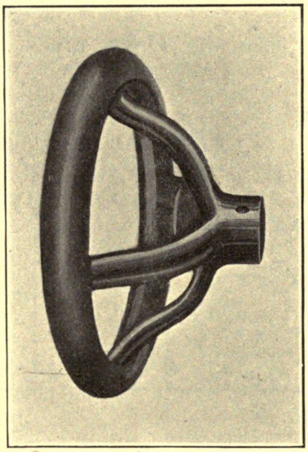
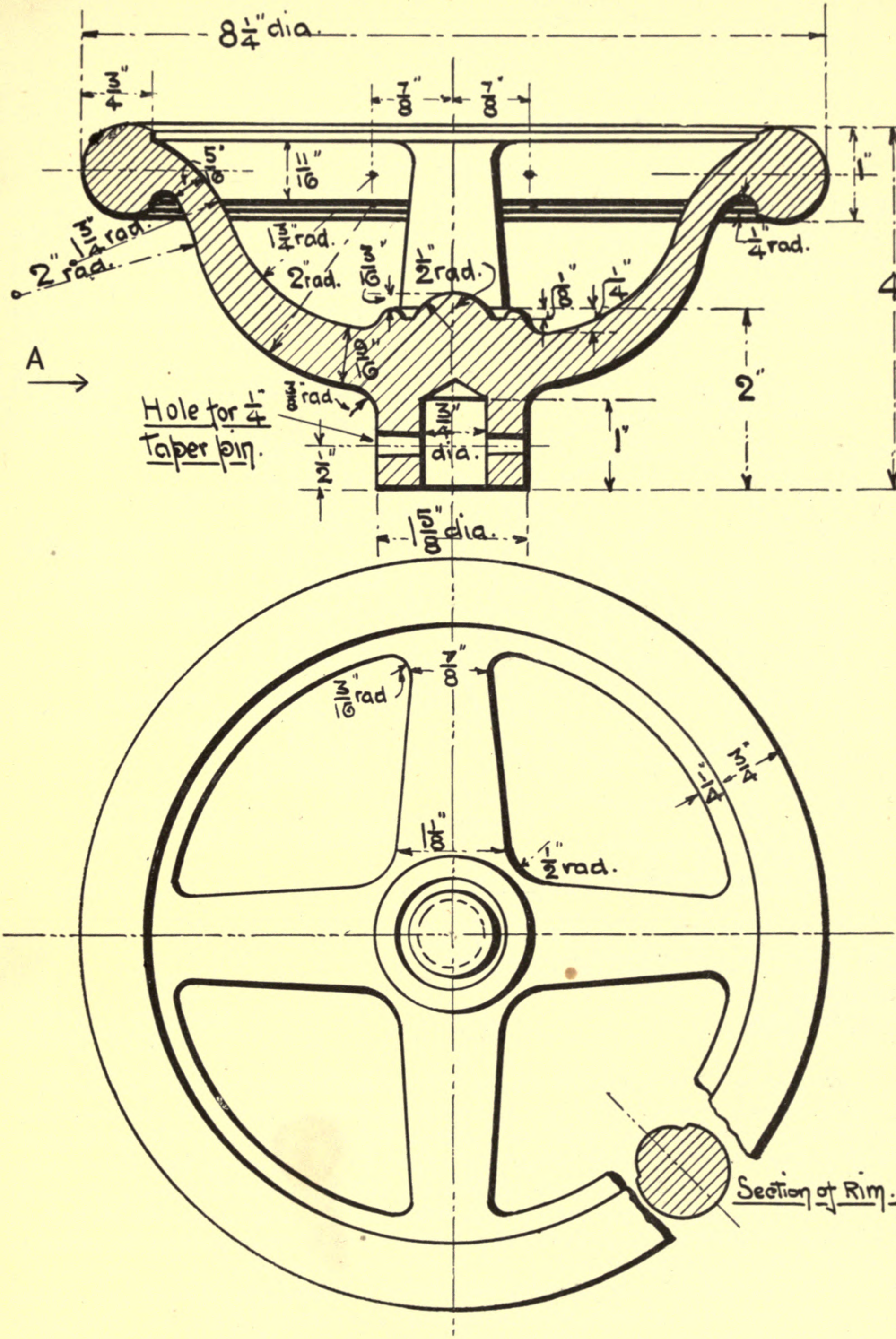


Fig. 28. – Hand Wheel.

Example.—Set out a similar hand wheel, the outside diameter being 160 millimetres, the total depth 51 millimetres, and the spindle 12·5 millimetres diameter. Give similar views, and complete with all necessary dimensions. Scale full size.



DRAWING No. 8.

SCALE FULL SIZE.

REGULATING HAND WHEEL.

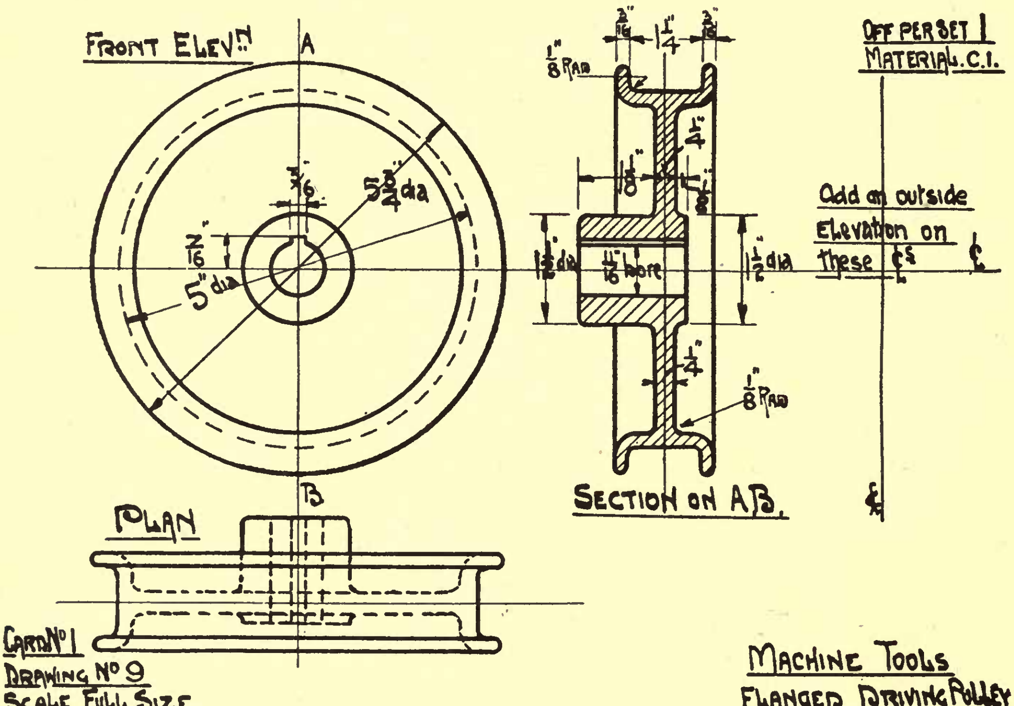
CAST IRON.

FLANGED DRIVING PULLEY.

Drawing No. 9.

Card No. 1.—This shows a pulley used for driving an arbor, carrying a number of metal-slitting saws. The front elevation and plan give all the information necessary for the making of the pulley, the section on AB giving a quicker comprehension of the construction than the plan.

Draw to a scale of full size the views shown, adding the outside elevation required.



Examples.—The line shaft makes 300 revolutions per minute, carries an 8 inches diameter pulley, driving a 16 inches diameter pulley on the countershaft, a 12 inches diameter pulley on which drives this 5-inch pulley. Neglecting all slip in the belts—(1) What is the rim speed of the saws in feet per minute, saws being 3 inches diameter? (2) What is the linear speed in feet per minute of each of the belts in the drive? (3) Allow a maximum tension on the belt of 100 lbs. What horse-power will this 1 inch wide belt transmit at the running speed of this example?

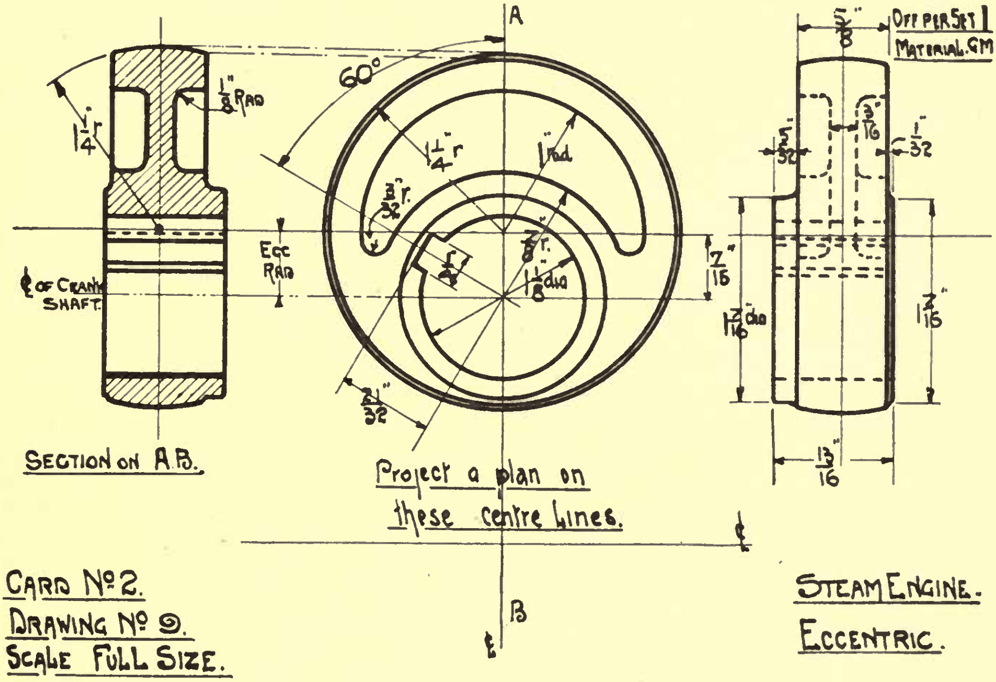
N.B.—A belt drives a pulley by friction of belt on surface of pulley. There is a difference of tension on the two sides of the belt, tight side and slack side, and the driving effort is equal to half the maximum tension in the belt, if we take the tension on the tight side as twice that on the slack side, which is nearly correct.

STEAM ENGINE ECCENTRIC.

Drawing No. 9.

Card No. 2.—Shows a simple eccentric for a small high-speed steam engine. All the information required can be given on the front and side elevations, but to give a more rapid idea of the exact form of the detail the front elevation and the section are the projections which would be used.

Draw to a scale of twice full size the views given, and add a plan on the centre lines indicated.



Note.—To get an automatic steam distribution through the cylinder of the engine, a valve is moved backwards and forwards on its seat, and the object of this detail is to convert rotary into reciprocating motion. It is really a small solid crank, the centre of the eccentric being the crank radius measured from the crank-shaft centre. The travel of the valve $= 2 \times$ radius of eccentric. The detail shown is called the eccentric sheave, and its motion is transmitted to the valve by a rod connected to a strap, made in halves bolted together, and working freely over the rim of the sheave.

HAND WHEEL FOR STEAM STOP-VALVE.

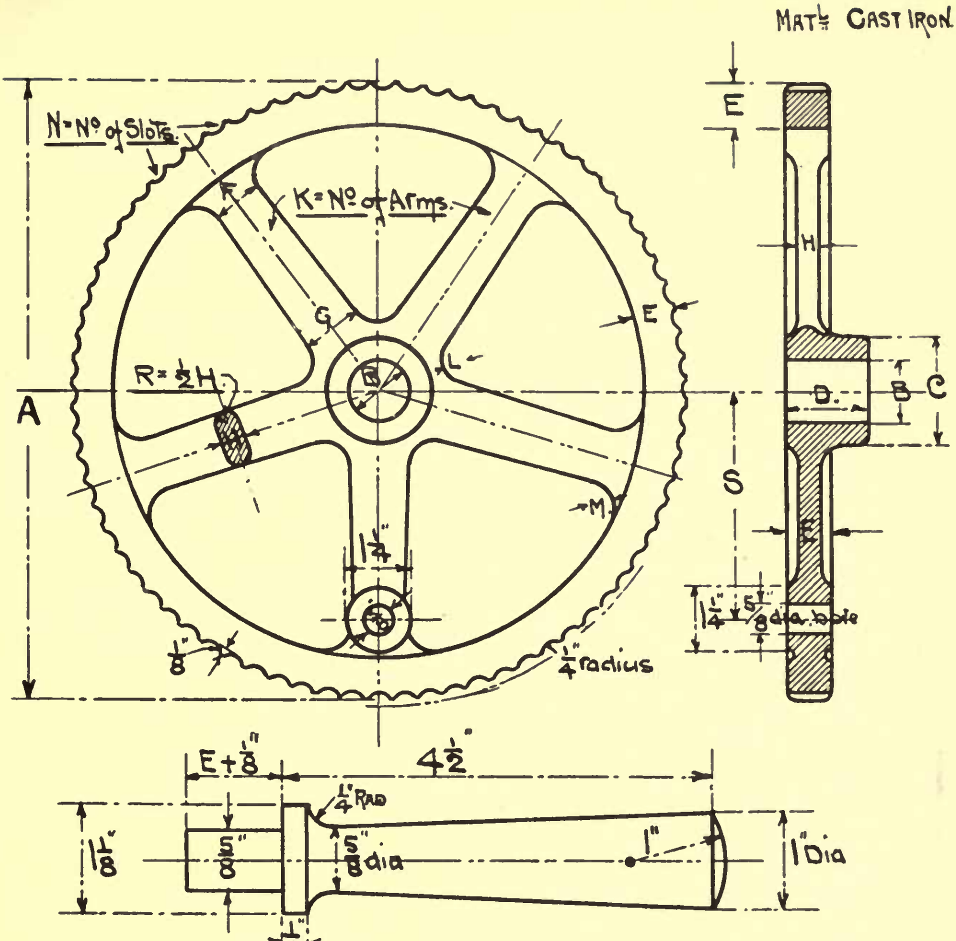
Drawing No. 10.

To prevent damage, a steam stop-valve should be opened slowly. It is opened against the steam pressure, and the effort required may be very great, depending upon the diameter of the valve, steam pressure on the valve, and the friction of the operating screw in its nut. The hand wheel shown has its rim surface roughened by a number of curved slots cut out as indicated, enabling it to be well gripped in the hand. The wheel is made of cast-iron, and the handle of mild steel. For wheels up to and including 8 inches diameter the handle is not fitted. The method of fixing the wheel to the spindle is omitted; for this refer to Drawing No. 29.

Fig. 29.—Hand Wheel.

Draw to a scale of full size, giving two views as indicated, and showing the handle in position, hand wheel suitable for a 3 inches diameter valve.

Example.—Where many details of the same type, but in different sizes, are made and used, they are standardised, and the particulars represented by a table as shown. In getting out such tables, the agreement of the numbers can be readily checked by plotting them in the form of a curve, as follows:—Draw a horizontal line; from one end measure off lengths corresponding to valve diameters—0, $1\frac{1}{4}$ inches, $1\frac{1}{2}$ inches, etc. At each point draw a perpendicular line, along which from the horizontal line set off heights corresponding to dimensions A, B, C, etc. Join all the A points, all the B points, etc. We get a series of curves showing the relation between the valve diameter and the various dimensions of the wheel.



A.	B.	C.	D.	E.	F.	G	H.	K.	L.	M.	N.	S.	Dia. of Valve.
5"	7/8"	1 5/8"	1 3/8	11/16"	13/16"	7/8"	3/8"	4.	9/16"	1/4"	24.	Not Required.	1¼"
6"	1"	1 7/8"	1½"	3/4"	7/8"	15/16"	7/16"	4.	11/16"	5/16"	30		1½"
7"	1"	1 7/8"	1½"	3/4"	7/8"	1"	7/16"	4.	5/8"	3/8"	36		2"
8"	1 1/8"	2"	1 5/8"	13/16"	15/16"	1 1/16"	1/2"	4.	9/16"	7/16"	40.		2½"
9"	1 1/8"	2"	1 5/8"	13/16"	15/16"	1 1/16"	1/2"	5.	1/2"	7/16"	44	2 13/16"	3"
11"	1¼"	2¼"	1¾"	7/8"	1"	1 1/8"	1/2"	5.	1/2"	1/2"	56	3¾"	4"
13"	1¼"	2¼"	1¾"	7/8"	1"	1 3/16"	1/2"	5.	1/2"	1/2"	64.	4¾"	5"
15"	1½"	2 5/8"	2"	1"	1 1/8"	1 5/16"	9/16"	5.	5/8"	9/16"	76	5 5/8"	6" & 7"
18"	1¾"	3"	2¼"	1 1/8"	1¼"	1½"	5/8"	6.	5/8"	5/8"	88	7"	8" & 9"
22"	2"	3 3/8"	2½"	1¼"	1 3/8"	1¾"	11/16"	6.	5/8"	3/4"	108	8 7/8"	10" & 12"

DRAWING No. 10. .STEAM STOP VALVES. HANDWHEELS.

RIVETS AND RIVETED JOINTS.

For permanent joints the most secure construction is obtained by using rivets. Bolts used in built-up structures subject to alternate stresses are always liable to work loose. For secure work, turned bolts and reamed holes must be employed, and the strength of the joint depends upon the shearing strength of the bolt. A rivet during contraction tightens the plates and holds them together by friction. The rivet must completely fill the hole, limiting the length of rivet which can be used to 4 inches. The rivet must be tight.

Tight rivets are easier to obtain in punched than in reamed or drilled work, as the roughness holds the rivet; but there is less certainty that the hole is filled. To get tight rivets the work must be well bolted together, and all burrs, chips, and drillings removed. All riveted work is carefully inspected to secure good work. The most common defect is loose rivets, which are detected by putting the finger, part on the rivet head, part on the plate, and striking the other head of the rivet with a hammer: looseness is immediately detected. The rivet head must be concentric with the shank and well formed.

Strength of Riveted Joints.—Friction is a most important factor. For security, the rivet area subject to shear is made as strong as the weakest section of the plate which is resisting tearing.

Diameter of rivet $= 1{\cdot}2 \times \sqrt{\text{thickness of plate}}$.

Distance between parallel rows of rivets $= 1{\cdot}75$ to $2 \times$ rivet diameter.

Overlap $= 1{\cdot}5 \times$ rivet diameter $+ \frac{1}{8}$ inch.

In an ordinary lap joint there is bending as well as shearing in the rivets. For butt joints, thickness of single cover-plate $= 1\frac{1}{8} \times$ plate thickness; for double cover-plates, each $= \frac{5}{8} \times$ plate thickness.

Pitch of rivets is usually two to three times the rivet diameter (refer fig. 30).

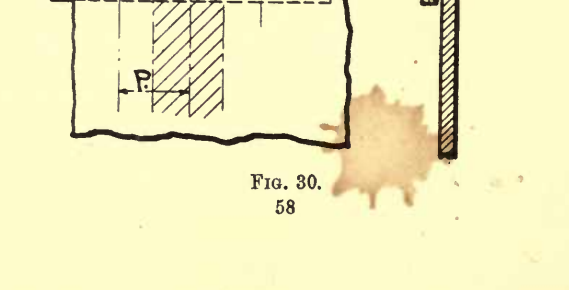


Fig. 30.

For a single-riveted lap joint making the shearing strength of the rivets equal to the tearing area of the plates—

$$\text{Strength to resist shearing} = \frac{\pi}{4} . d^2 . fs.$$

$$\text{Strength to resist tearing} = (p-d) . t . ft.$$

$$\therefore \quad (p-d) . t . ft = \frac{\pi}{4} . d^2 . fs.$$

Consider $fs = ft$. From t the plate thickness d is obtained, and hence p, the pitch.

$$\text{The efficiency of the joint} = \frac{\text{effective width of plate}}{\text{width of solid plate}} = \frac{p-d}{p}.$$

Draw to a scale of half full size the riveted joints given in fig. 31, and set out full size a 1 inch diameter rivet with (1) round, (2) countersunk, and (3) cone head.

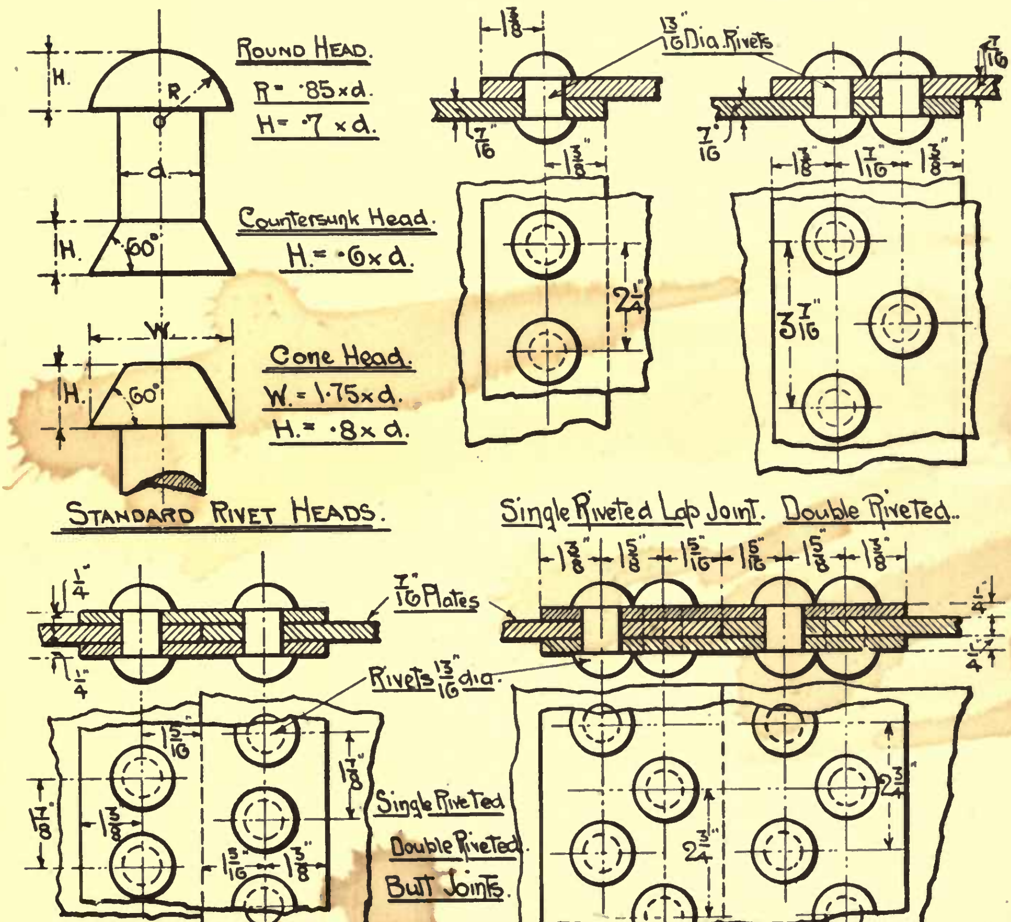


FIG. 31.

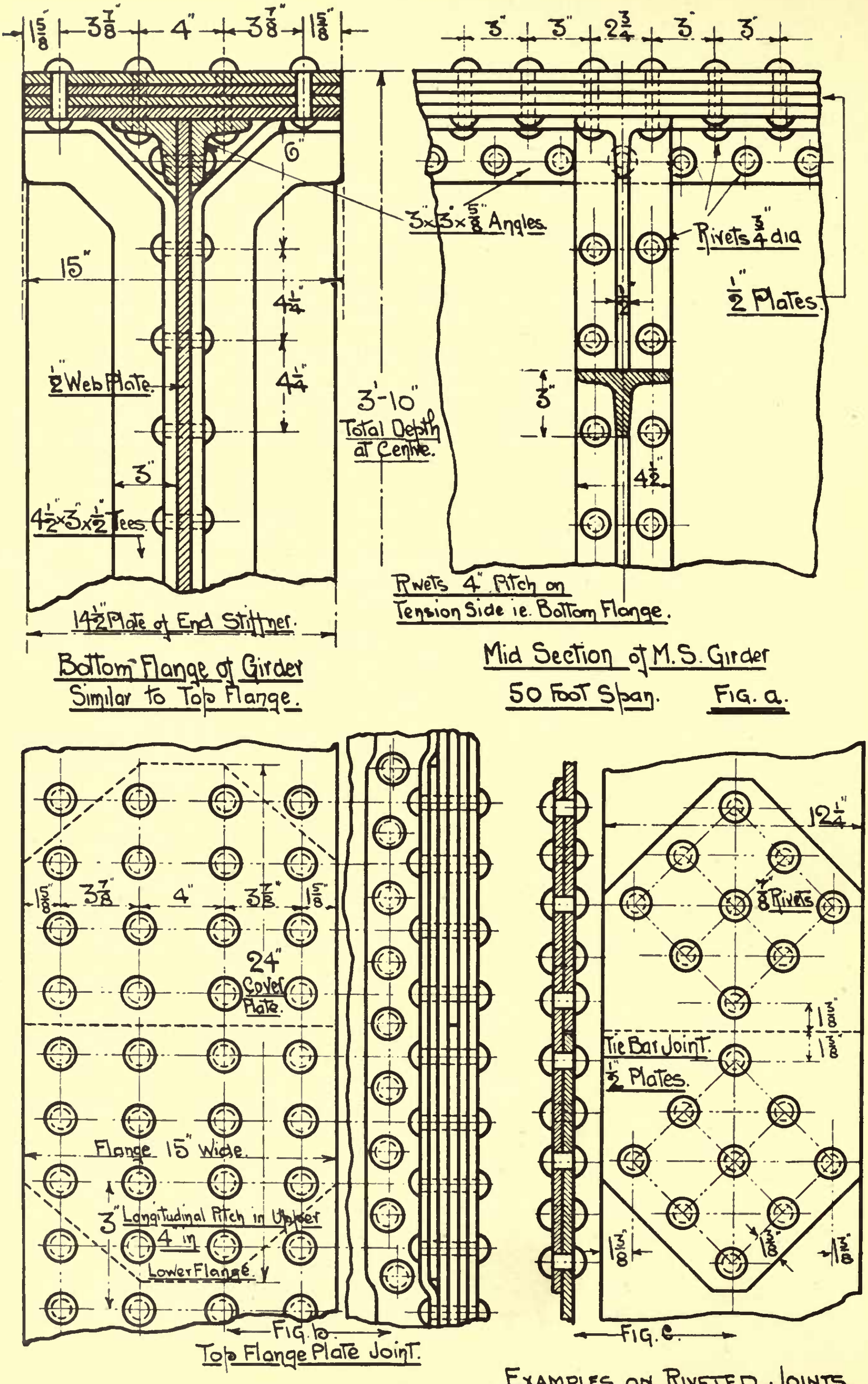

3x3x5/8 Angles.
Rivets 3/4 dia
1/2 Plates.
15"
1/2 Web Plate.
3'-10"
Total Depth at Centre.
4 1/2 x3x1/2 Tees.
14 1/2 Plate of End Stiffner.
Rivets 4" Pitch on Tension Side ie. Bottom Flange.
Bottom Flange of Girder Similar to Top Flange.
Mid Section of M.S. Girder
50 Foot Span.
FIG. a.
24" Cover Plate.
Flange 15" Wide.
3" Longitudinal Pitch in Upper
4 in Lower Flange.
FIG. b.
Top Flange Plate Joint.
12 1/4"
7/8 Rivets
Tie Bar Joint.
1/2 Plates.
FIG. c.
EXAMPLES ON RIVETED JOINTS

Fig. 32.

Draw to a scale of quarter full size the details given in fig. 32 :—

1. The mid section of a mild-steel girder, 50-foot span.
2. Flange plate joint for the same girder.
3. Tie bar joint.

Examples—

1. Explain the different ways in which a single-riveted lap joint may fracture.
2. What is the difference between zigzag and chain riveting? State the relative advantages of the two methods.
3. Describe, with sketches, the various ways of jointing up the segments or rings of the flue tube of a boiler.
4. Why are punched holes sub-punched, and then reamed out to size?
5. Sketch the shape of rivet head produced by having (1) too much, (2) too little metal in the shank, and (3) by heating the point of the rivet only instead of uniformly throughout.
6. What methods may be adopted to detect loose rivets when examining girder work?
7. Describe, with sketch, a built-up box girder.
8. A rivet is made of Muntz metal, and is to be riveted over cold to form a countersunk head. Show the shape the rivet end is turned to, and give dimensions for a 1 inch diameter rivet, and assumed countersink.

SCREW THREADS.

In designing or getting out machinery of any kind, it is not possible to proceed very far before finding out that some sort of detail is required to hold the several parts together. A screw thread is an essential part of many of these details. (Refer to fig. 33.)

Take a round bar of metal, fixed so that it can be rotated at a uniform rate between a pair of centres. Take a sharp-pointed tool, mounted so as to touch the surface of this bar, and so that it can be moved along at a uniform rate parallel to the axis of the bar.

1. Let the bar rotate and the tool remain fixed. A line is traced round the circumference of the bar.
2. Let the bar remain fixed and the tool slide. A straight line is traced along the bar.
3. Let the bar rotate and the tool slide at the same time, the tool passing from A to B during the time the bar makes one complete turn. A line is traced on the surface, having a curved appearance as shown, and called a helix.

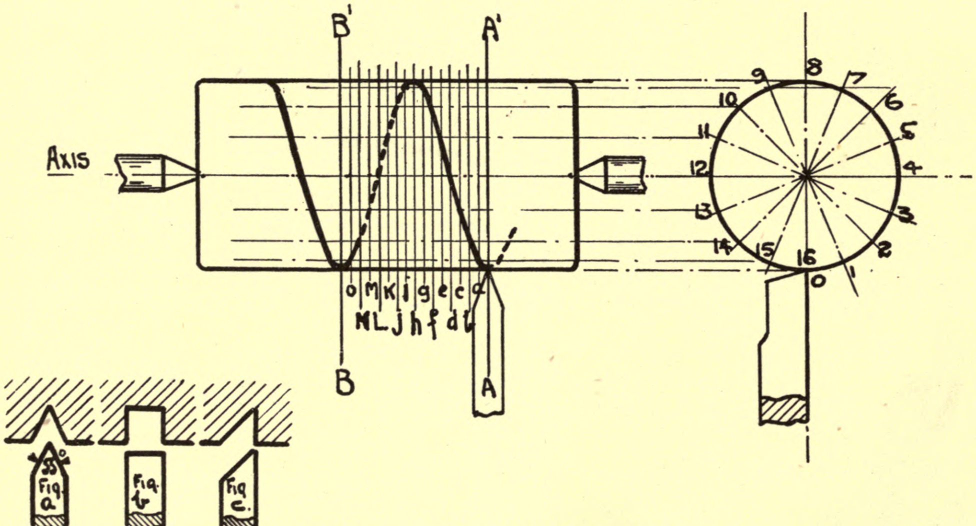


Fig. 33.—Generation of Screw Thread.

A construction which enables the line obtained to be drawn is as follows:—

Divide the circumference in the end view of the bar into an equal number of parts, say sixteen. Divide the pitch AB into the same number of equal parts. While the tool slides from A to a, the bar turns past the tool from O to 1. A projection line through 1, parallel to the axis, cuts the perpendicular through a and gives one point on the curve. Find other points on the curve in the same way; join all the points obtained, giving the helix required.

The distance AB is called the **pitch** of the helix or thread, and between the lines AA′, BB′ we have one complete thread.

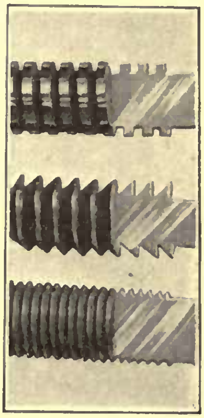


FIG. 34.—Screw Threads.

Standard Screw Threads.—So far a line only has been traced on the surface of the bar. For a practical detail, some form of groove is required, depending upon the use of the detail. Thus, if we feed into the bar a tool formed as shown in fig. 33 (a), the groove obtained is called a **vee** thread; if as in fig. 33 (b), a **square** thread; and if as in fig. 33 (c), a **buttress** thread. The vee thread is the one most widely used, and for cheapness of production, ease of renewal and replacement, it is advantageous to work to definite standards giving—

1. Number of pitches AB in 1 inch of length.
2. The section or form of the groove.

Vee Threads: Whitworth Standard.—*Form of Groove, fig.* 35.—The angle between the sides of the thread is 55°. If the thread were cut to a sharp vee at the bottom to give a sharp top, the total depth of the thread would be

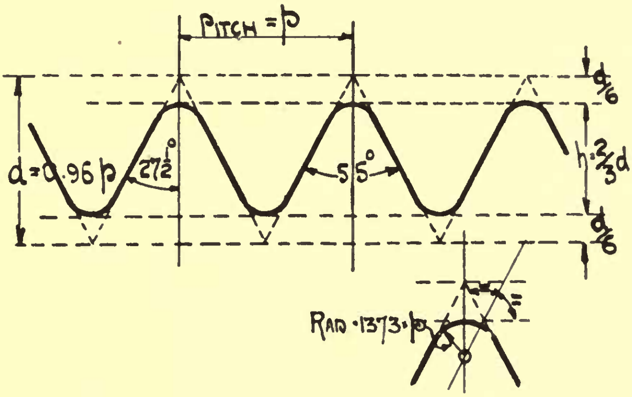


FIG. 35.—Whitworth Standard Vee Thread.

0·96 × pitch. The thread is rounded off top and bottom, leaving the depth = 0·64 × pitch. The outside diameter of the bolt corresponds to the diameter over the top of the actual thread. The pitch is $\dfrac{1}{\text{number of threads per inch}}$ as given in the following table:—

Number of Threads per Inch: Whitworth Vee Standard.

For Bolts.		Gas and Water Pipes.			Hydraulic Piping.		
Diameter. Inches.	Threads per inch.	Internal Diameter. Inches.	Threads per inch.	External Diameter. Inches.	Internal Diameter. Inches.	Threads per inch.	External Diameter for 6000 lbs. per sq. inch.
$\frac{1}{16}$	60	$\frac{1}{8}$	28	·382	$\frac{1}{8}$	14	$\frac{3}{4}$
$\frac{3}{32}$	48	$\frac{1}{4}$	19	·518	$\frac{3}{8}$	14	$\frac{7}{8}$
$\frac{1}{8}$	40	$\frac{3}{8}$	19	·656	$\frac{1}{2}$	14 or 11	$1\frac{1}{8}$
$\frac{3}{16}$	24	$\frac{1}{2}$	14	·826	$\frac{5}{8}$	14 or 11	$1\frac{1}{4}$
$\frac{1}{4}$	20	$\frac{5}{8}$	14	·902	$\frac{3}{4}$	11	$1\frac{3}{8}$
$\frac{5}{16}$	18	$\frac{3}{4}$	14	1·04	All sizes above.	11	
$\frac{3}{8}$	16	$\frac{7}{8}$	14	1·19			
$\frac{7}{16}$	14	1	11	1·31			
$\frac{1}{2}$	12	All sizes above.	11				
$\frac{9}{16}$	12						
$\frac{5}{8}$	11						
$\frac{11}{16}$	11						
$\frac{3}{4}$	10						
$\frac{13}{16}$	10						
$\frac{7}{8}$	9						
$\frac{15}{16}$	9						
1	8						
$1\frac{1}{8}$	7						
$1\frac{1}{4}$	7						
$1\frac{3}{8}$	6						
$1\frac{1}{2}$	6						

For Bolts.—The list is continued, advancing by eighths up to 6 inches diameter having $2\frac{1}{2}$ threads per inch.

Number of square threads per inch is half the number of vee threads on a bolt of the same diameter.

Threaded ends of steam and gas pipes tapered $\frac{3}{4}$ inch per foot.

The above table includes all sizes. The use of bolts of a diameter not usually kept in stock, such as $\frac{11}{16}$ or $\frac{13}{16}$ inch, must be carefully avoided. Similarly, for gas threads, the use of $\frac{7}{8}$ inch gas would probably lead to trouble. Before using any particular size, make sure that the material and tackle are easily obtainable.

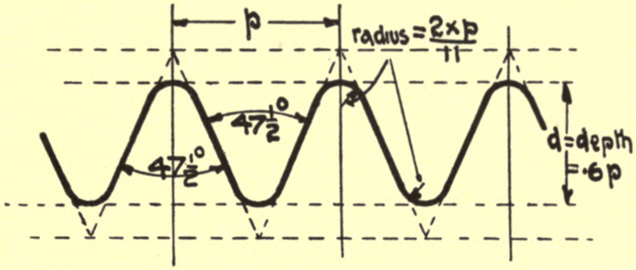
Fine Threads.—For bolts subjected to excessive shock and vibration the above list gives a thread too coarse for satisfactory use, in which case the number of threads per inch for any diameter is increased, and we have:—

Diameter . .	$\frac{1}{4}$	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{7}{16}$	$\frac{1}{2}$	$\frac{9}{16}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{7}{8}$	1	$1\frac{1}{8}$	$1\frac{1}{4}$	$1\frac{3}{8}$	$1\frac{1}{2}$ inches.
Threads per inch .	25	22	20	18	16	16	14	12	11	10	9	9	8	8.

Bolts above $1\frac{1}{2}$ inches diameter are considered somewhat special, and as the small number of threads per inch makes such a large groove, that is, cuts away so much metal, the standard list is departed from, and all such bolts threaded with, say, six threads per inch.

Vee Threads: British Association (B.A.) Standard.—*Form of Groove, fig.* 36.—For work such as small precision machinery and electrical fittings a range of small screws below $\frac{1}{4}$ inch diameter is required, and B.A. screws are used. The size is denoted by a number. The angle between the sides of the

thread is 47·5°, the depth of the thread ·6 by pitch, and the top and bottom rounded off.



BRITISH ASSOCIATION STANDARD THREAD.

FIG. 36.

Number of Threads per Inch: B.A. Standard.

Number.	Millimetres.		Diameter.		Pitch. Mils.	Threads per inch.
	Diameter.	Pitch.	Mils.	Inches, approx.		
0	6·0	1·00	236	$\frac{15}{64}$ Full	39·4	25·4
1	5·3	·90	209	$\frac{13}{64}$ F.	35·4	28·2
2	4·7	·81	185	$\frac{3}{16}$ Bare	31·9	31·4
3	4·1	·73	161	$\frac{5}{32}$ F.	28·7	34·8
4	3·6	·66	142	$\frac{9}{64}$ F.	26·0	38·5
5	3·2	·59	126	$\frac{1}{8}$ F.	23·2	43·0
6	2·8	·53	110	$\frac{7}{64}$ F.	20·9	47·9
7	2·5	·48	98	$\frac{3}{32}$ F.	18·9	52·9
8	2·2	·43	87	$\frac{3}{32}$ B.	16·9	59·1
9	1·9	·39	75	$\frac{5}{64}$ F.	15·4	61·5
10	1·7	·35	67	$\frac{1}{16}$ F.	13·8	72·6
11	1·5	·31	59	$\frac{1}{16}$ B.	12·2	81·9
12	1·3	·28	51	$\frac{3}{64}$ F.	11·0	90·7
13	1·2	·25	44	$\frac{3}{64}$ B.	9·8	101
14	1·0	·23	39	$\frac{3}{64}$ B.	9·1	110
15	·90	·21	35	$\frac{1}{32}$ F.	8·3	121
16	·79	·19	31	$\frac{1}{32}$	7·5	134
up to 25						

To avoid the large stock of material involved by the use of all the above sizes, firms specify the use of particular numbers only, such as all even sizes up to 16.

Vee Threads: Institute of Cycle Engineers' Standard.—*Form of Groove, fig.* 37.—This is a 60° thread with the tops and bottoms rounded as shown. The following table gives the number of threads per inch for different diameters:—

Diameter. Inches.	Threads per inch.	Diameter. Inches.	Threads per inch.	Diameter. Inches.	Threads per inch.
·056	62	·154	40	·375	26
·064	62	·175	32	·5625	26
·072	62	·1875	32	1·000	24
·080	62	·25	26	1·29	24
·092	56	·266	26	1·37	24
·104	44	·281	26	1·4375	24
·125	40	·3125	26	1·5	24

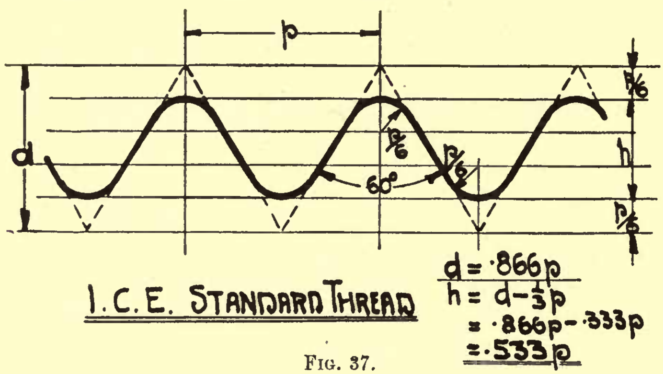


Fig. 37.

Vee Threads: United States Standard.—*Form of Groove, fig.* 38.—Compared with the Whitworth thread, the great advantage of this thread is the ease and economy with which the angle of 60° can be obtained; also, the

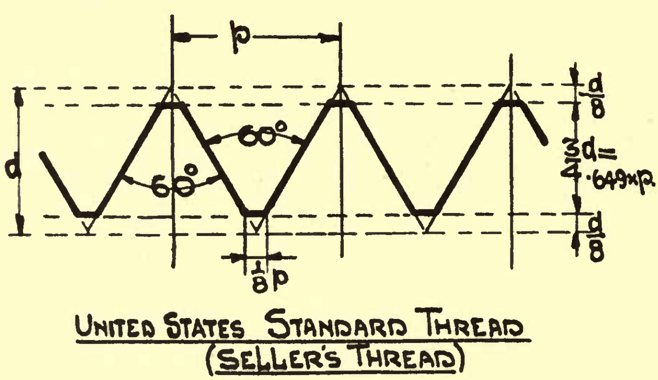


Fig. 38.

top and bottom of the thread being flat, a more perfect thread can be cut. On the other hand, the friction and bursting action on the nut are greater, and the screwed bar has a smaller diameter at the bottom of the thread than the Whitworth standard, while the sharp corners at the root of the thread are points of weakness from which fractures may start, and the tops of the threads will more readily get damaged by rough usage.

Number of Threads per Inch: United States Standard.

Diameter. Inches.	Threads per inch.	Diameter. Inches.	Threads per inch.	Diameter. Inches.	Threads per inch.
$\frac{1}{4}$	20	$\frac{7}{8}$	9	$1\frac{7}{8}$	5
$\frac{5}{16}$	18	1	8	2	$4\frac{1}{2}$
$\frac{3}{8}$	16	$1\frac{1}{8}$	7	$2\frac{1}{8}$	$4\frac{1}{2}$
$\frac{7}{16}$	14	$1\frac{1}{4}$	7	$2\frac{1}{4}$	$4\frac{1}{2}$
$\frac{1}{2}$	13	$1\frac{3}{8}$	6	$2\frac{3}{8}$	4
$\frac{9}{16}$	12	$1\frac{1}{2}$	6	$2\frac{1}{2}$	4
$\frac{5}{8}$	11	$1\frac{5}{8}$	$5\frac{1}{2}$	$2\frac{5}{8}$	4
$\frac{3}{4}$	10	$1\frac{3}{4}$	5		

The actual list goes up to 6 inches diameter, with $2\frac{1}{4}$ threads per inch. It is not usual to cut such coarse pitches. If the limit be fixed at 4 threads per inch, then all bars above $2\frac{3}{4}$ inches diameter would be screwed 4 threads per inch, and denoted as a fine thread to show that it is not according to the standard list.

Vee Thread: International and French Standards.—To obtain a universal standard for screw threads the International system (S.I.) has been suggested. It is a modification of the French system, and all dimensions are in millimetres.

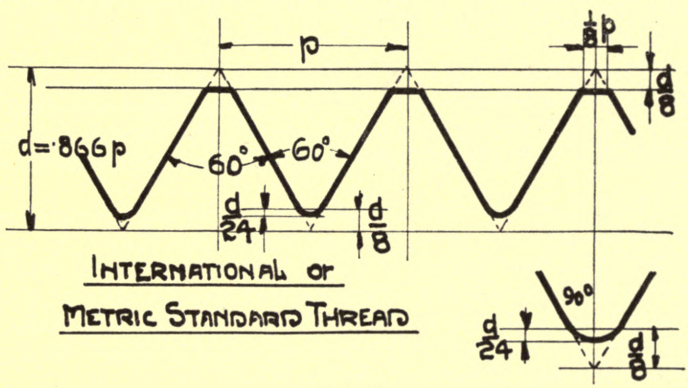


FIG. 39.

The form of groove is shown in fig. 39, the pitch of the threads being, on the—

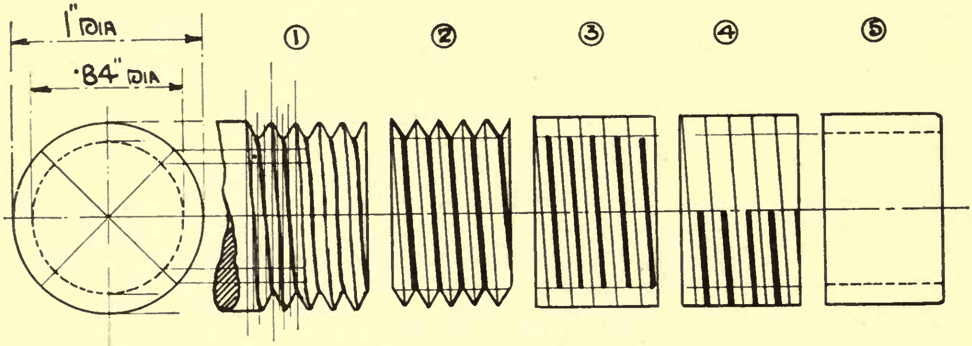
International System.

Diameter of Bolt.	Pitch.	Dia-meter.	Pitch.	Dia-meter.	Pitch.	Dia-meter.	Pitch.
3	0·55	11	1·5	30	3·5	60	5·5
3·5	0·55	12	1·75	33	3·5	64	6
4	·7	14	2	36	4	68	6
5	·85	16	2	39	4	72	6·5
6	1·0	18	2·5	42	4·5	76	6·5
7	1·0	20	2·5	45	4·5	80	7·0
8	1·25	22	2·5	48	5	...	...
9	1·25	24	3·0	52	5	...	...
10	1·5	27	3·0	56	5·5	...	...

French Standard.

Dia-meter.	Pitch.	Dia-meter.	Pitch.
3	0·5	42	4·5
4	0·75		
6	1·0	48	5·0
10	1·5		
14	2·0	Sizes in between have the same pitch as the next lower number.	
18	2·5		
24	3·0		
30	3·5		
36	4·0		

Representation of a Screw Thread (fig. 40).—A thread is set out on a bar 1 inch diameter, the form of groove being Whitworth standard (fig. 35), the number of threads per inch eight, the diameter at the bottom of the threads being 0·84 inch.



METHODS OF SHEWING A SCREW THREAD.

FIG. 40.

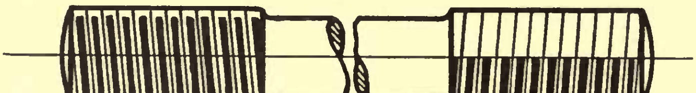
Part (1).—The groove is set out to the data given in fig. 35. The lines corresponding to the extreme top and bottom of the thread are drawn by the method given in fig. 33, noting that the bottom of the thread is indicated by the helix traced on the circle representing the bottom of the thread, as seen in the end view.

Part (2).—Two lines are drawn corresponding to the tops and bottoms of the thread, and the pitch is set out along both these lines. A reference to fig. 33 will show that the vees on one side are half a pitch in front of those on the other side of the centre line. The sides of the thread are straight lines joining the top of the thread to the bottom; and instead of the helix, straight lines are drawn joining the tops of the vees on opposite sides. Similarly, lines are drawn for the bottom of the thread.

Part (3) is similar to Part (2), but the lines forming the sides of the threads are left out. This is the usual method of representation. Until a student has obtained some practice, the lines representing the depth of the thread should be drawn, and the pitch set out accurately before drawing in the cross lines. Afterwards lines representing screw threads may be drawn in by eye.

Parts (4) and (5) are further methods used to indicate that a bar is to be screwed.

Right-hand Thread.—The right-hand thread is usually used. If the bolt be taken in the left hand and turned by the right in a clockwise direction, it will



RIGHT HAND THREAD LEFT HAND THREAD

FIG. 41.

work itself inwards. The lines indicating the threads slope upwards from left to right, as shown in fig. 41.

Left-hand Thread.—This is only used in special cases. If treated as above, it would work itself out of the hand. The lines representing the thread slope in the opposite direction to those representing a right-hand thread, as shown in fig. 41.

Note.—The right-hand thread is indicated by the method shown in Part (3) of fig. 40, and the left-hand thread by the method shown in Part (4).

Square Threads.—The number of square threads per inch is usually half the number of Whitworth vee threads, for a bolt of the same diameter. This

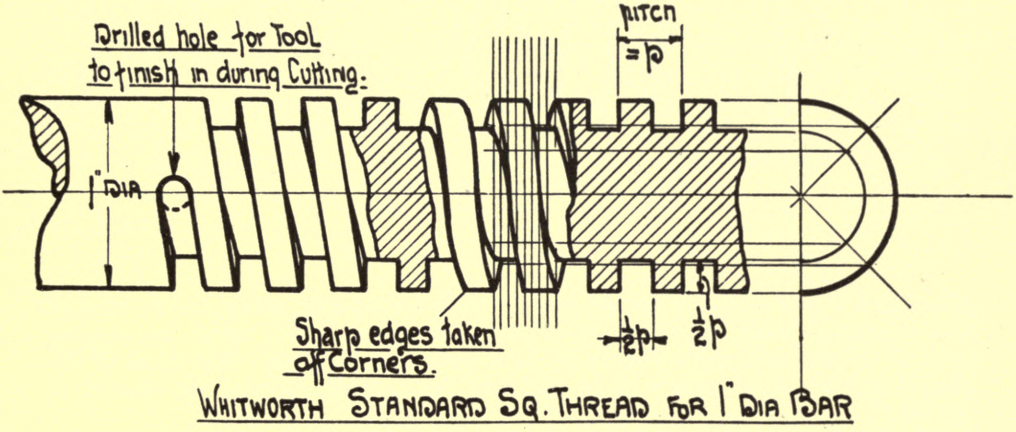


FIG. 42.

thread is used, as in machine tools, for giving motion and transmitting energy. The reaction between the screw and its nut is almost parallel to the axis of the screw, that is, the force is practically in the direction in which motion is to be produced, and loss due to friction is small. The form of the groove makes it much weaker than the vee thread, which is mainly used for holding purposes.

Fig. 42 shows a standard right-hand square thread for a 1 inch diameter bar. The correct representation of the thread is obtained by an application of

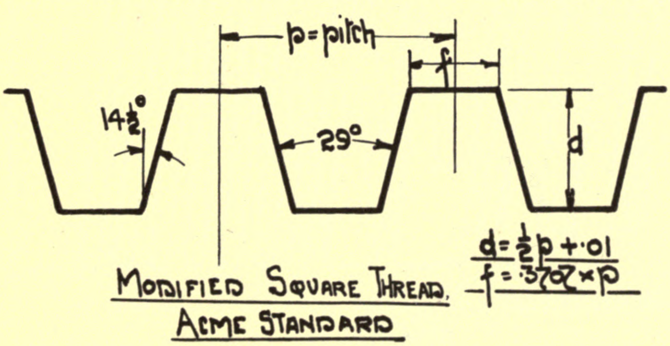
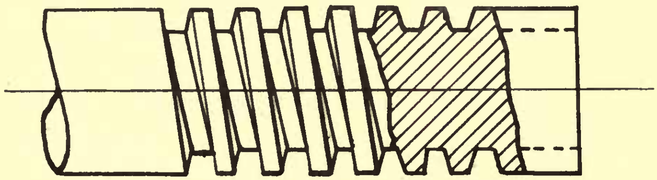


FIG. 43.

the method described in fig. 33, and as indicated. The more usual way of representing it is by means of straight lines, as indicated at the finishing end of the thread. Square-thread screws may be cut either right or left hand as desired. In some special cases both a right- and a left-hand thread are cut on the same spindle.

Modified Square Thread (fig. 43).—The ordinary square thread has perpendicular sides, which make it difficult to cut. This section is stronger than the ordinary thread. The nut can more easily be adjusted for any wear taking



VIEW of THREAD AS CUT.

FIG. 44.

place, and where a square thread is used with a split nut, which has to engage and disengage with the screw, as in the leading-screw of a lathe, the sloping sides of the thread enable this to be done with greater ease. The form of the thread groove is as shown in fig. 43, and the outside view of the thread in fig. 44.

Double Square-threaded Screw (fig. 45).—Very often an adjusting screw having a square thread is required to give a quick travel to a sliding piece. If the force transmitted is not great, a screw of small diameter has sufficient

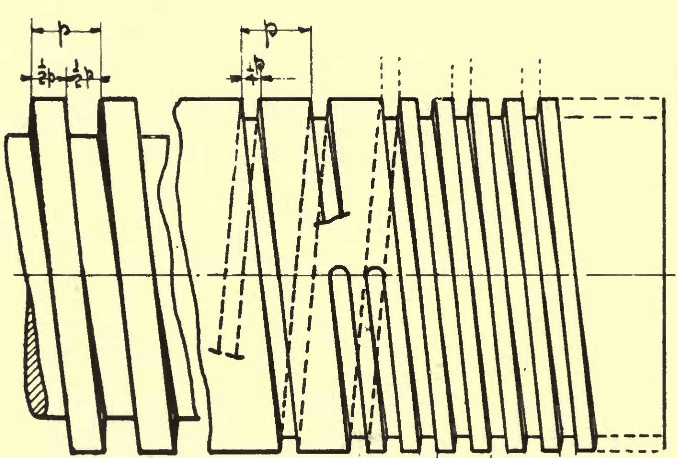


FIG. 45.

strength. The quick travel means a large pitch (the nut will travel a distance equal to the pitch for one revolution of the screw, if the nut is free to slide, and the screw free to rotate only), and it is not possible to cut the screw to the standard dimensions. This is overcome by using double- or even triple-threaded screws. Again, as a screw is required to transmit force and motion—that is, energy—the cutting of a standard square thread might reduce the effective area of the bar to an undesirable extent.

Example.—A bar is 2·50 inches diameter; area, 4·91 square inches; correct number of Whitworth vee threads per inch, 4; number of square threads, 2; pitch of thread, ·5 inch; depth of thread, ·25 inch; diameter of bar at bottom of thread, 2 inches; area, 3·14 square inches; reduction of area, 1·77 in 4·91—that is, 36 per cent.

In such a case the standard pitch is retained, and a thread is cut (fig. 45) of this pitch, but the width of the groove and the depth are made half those of a standard thread. Then in the thick piece of metal left an exactly similar thread is cut, but half a pitch out with the first thread. A double thread is thus obtained, which gives a satisfactory bearing area and strength of thread, and does not unduly reduce the strength of the bar.

EXAMPLES ON SCREW THREADS.

Drawing No. 11.

MAKE a standard drawing consisting of four equal cards, and from the data given on screw threads set out the following:—

Card No. 1.

(*a*) Draw a helix $1\frac{1}{2}$ inches pitch on a bar 3 inches diameter, showing two complete threads. (Refer to fig. 33.)

(*b*) Plot curves showing the relation between the number of threads per inch and the diameter of the screwed bar for Whitworth, B.A., United States, and International standards (converting the dimensions of this latter one to inches for the purpose). Take a vertical scale of 1 inch = 12 threads, and a horizontal scale of four times full size, *i.e.* ·25 inch is represented by 1 inch.

Card No. 2.

(*a*) Set out full size the section of a Whitworth standard vee thread, taking a pitch of 2 inches.

(*b*) With same pitch, set out a United States standard flat-topped vee thread, scale full size, and verify that depth of vee is $0{\cdot}866 \times$ pitch, the actual height of the thread is $0{\cdot}649 \times$ pitch, and that the width of the flat is $0{\cdot}125 \times$ pitch.

Card No. 3.

1. A standard square thread, pitch $\frac{1}{2}$ inch, is cut in a bar 2·5 inches diameter. Draw three lengths, each 2·5 inches long, showing (*a*) a section through the axis of the bar; (*b*) correct outside view of the thread; (*c*) outside view of the thread as usually represented.
2. Represent a double square thread 1 inch pitch, cut on a bar 1·5 inches diameter.

Card No. 4.

(*a*) Sketch and describe a chaser. Explain how it is used.

(*b*) Make a line diagram showing the arrangement of a lathe to cut a screw thread.

(*c*) What is a centre and thread gauge? Give a sketch, and explain how it is used in grinding and setting screw-cutting tools.

Bolts and Nuts.

Whitworth Standard Bolts and Nuts.

Diameter of bolt and size of nut.	1/16	3/32	1/8	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16	3/4	13/16	7/8	15/16	1 ins.
	1·6	2·4	3·2	4·7	6·4	7·9	9·5	11·1	12·7	14·3	15·9	17·5	19·0	20·7	22·0	23·9	25·4 m/m.
No. of threads per inch.	60	48	40	24	20	18	16	14	12	12	11	11	10	10	9	9	8
Diameter at bottom of thread.	·041	·067	·093	·134	·186	·241	·295	·346	·393	·456	·508	·571	·622	·684	·733	·795	·840
Area at bottom of thread.	·0013	·0035	·0067	·014	·027	·045	·068	·094	·121	·163	·202	·256	·303	·367	·422	·496	·554
Nuts across flats.	7/32	9/32	11/32	7/16	33/64	38/64	45/64	53/64	29/32	1 1/64	1 3/32	1 13/64	1 19/64	1 25/64	1 31/64	1 37/64	1 43/64
Nuts across corners.	1/4	21/64	25/64	33/64	38/64	11/16	13/16	61/64	1 1/16	1 5/32	1 17/64	1 25/64	1 1/2	1 39/64	1 45/64	1 13/16	1 59/64
Diameter of tapping-hole.	3/64	5/64	3/32	9/64	3/16	1/4	19/64	23/64	13/32	15/32	33/64	37/64	5/8	11/16	47/64	51/64	27/32
Thickness of bolt-head.	1/16	3/32	7/64	11/64	7/32	9/32	21/64	25/64	7/16	1/2	35/64	39/64	21/32	23/32	49/64	53/64	7/8

Diameter of bolt and size of nut.	1 1/8	1 1/4	1 3/8	1 1/2	1 5/8	1 3/4	1 7/8	2	2 1/8	2 1/4	2 3/8	2 1/2	2 5/8	2 3/4	2 7/8	3 ins.
	28·6	31·7	34·9	38·1	41·3	44·4	47·6	50·8	53·9	57·1	60·3	63·5	66·7	69·8	73·0	76·2 m/m.
No. of threads per inch.	7	7	6	6	5	5	4·5	4·5	4·5	4	4	4	4	3·5	3·5	3·5
Diameter at bottom of thread.	·942	1·07	1·16	1·29	1·37	1·49	1·59	1·71	1·84	1·93	2·05	2·18	2·30	2·38	2·51	2·63
Area at bottom of thread.	·697	·893	1·06	1·29	1·47	1·74	1·99	2·31	2·66	2·92	3·31	3·73	4·17	4·46	4·92	5·44
Nuts across flats.	1 55/64	2 3/64	2 7/32	2 13/32	2 37/64	2 3/4	3 1/64	3 5/32	3 11/32	3 35/64	3 3/4	3 57/64	4 3/64	4 3/16	4 11/32	4 17/32
Nuts across corners.	2 5/32	2 23/64	2 35/64	2 25/32	2 31/32	3 3/16	3 31/64	3 5/8	3 55/64	4 3/32	4 21/64	4 1/2	4 43/64	4 53/64	5 1/64	5 15/64
Diameter of tapping-hole.	61/64	1 1/16	1 11/64	1 19/64	1 3/8	1 1/2	1 19/32	1 23/32	1 27/32	1 15/16	2 1/16	2 3/16	2 5/16	2 3/8	2 1/2	2 5/8
Thickness of bolt-head.	63/64	1 3/32	1 13/64	1 5/16	1 27/64	1 17/32	1 41/64	1 3/4	1 55/64	1 31/32	2 5/64	2 3/16	2 19/64	2 13/32	2 1/2	2 5/8

Depth of nut equals the diameter of bolt.

The detail used for holding two or more pieces together has a shape varied to suit the purpose for, and position in, which it is to be used.

Bolts.—The common form of the detail is a bar of metal, with a head formed on one end, and a screw thread on the other end.

The length of a bolt is taken as the distance from the under side of the head to the end, and does not include the rounding.

The properties by which a bolt is known are: the shape of the head, the character of the neck, and the standard to which it is screwed. Thus:—

Fig. 46 shows a Whitworth standard, hexagon head, round neck bolt ½ inch diameter, 2¼ inches long, screwed 1¼ inches.

Fig. 47 shows a Whitworth standard square head and neck bolt, ⅝ inch diameter, 1¾ inches long, screwed ¾ inch.

For turning a bolt in a cramped position, the hexagon or six-sided head is convenient. As a special tool, called a spanner, is used for tightening them up, it is essential that bolt-heads should be of some standard size for each bolt diameter.

Bolt-heads, *Whitworth Standard.*—

For a hexagon head the width across the flats } is given approximately by
For a square head the width across the flats } the rule—

Width w = diameter of bolt + half diameter of bolt + ⅛ of an inch.

Thickness of bolt-head is equal to half the width across the flats.

This approximate rule is useful in drawing, saving as it does continual reference to the accurate table. At the same time, spanners made to this rule do not fit bolt-heads made strictly to the Whitworth standard list, and the discrepancy is the cause of much annoyance, due to spanners not fitting bolt-heads or nuts.

HEXAGON BOLT-HEADS—WHITWORTH STANDARD.

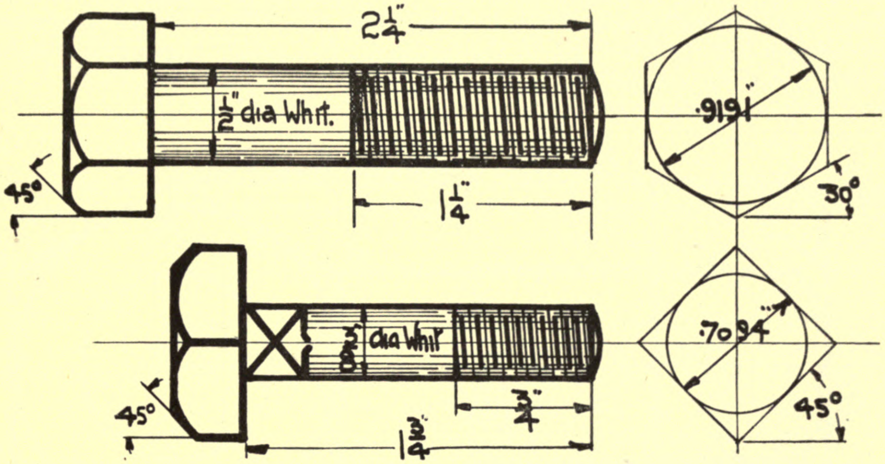
Bolt Diameter. Inches.	Width across Flats.		Thickness of Bolt-head.		Distance across Corners.	
	Standard.	Approx. Rule.	Standard.	Approx.	Standard.	Approx.
1/16	·212	·219	·055	·110	·245	·250
3/32	·280	·266	·082	·133	·323	·305
⅛	·338	·312	·109	·106	·390	·359
3/16	·448	·406	·164	·203	·517	·467
¼	·525	·500	·219	·25	·606	·575
5/16	·601	·594	·273	·297	·694	·682
⅜	·709	·687	·328	·343	·819	·790
7/16	·820	·781	·383	·390	·947	·898
½	·919	·875	·437	·437	1·061	1·004
⅝	1·10	1·062	·547	·531	1·271	1·221
¾	1·30	1·25	·656	·625	1·502	1·437
⅞	1·479	1·437	·766	·718	1·707	1·656
1	1·67	1·625	·875	·817	1·928	1·868
1⅛	1·86	1·81	·984	·905	2·148	2·083
¼	2·05	2·00	1·094	1·00	2·365	2·3
1⅜	2·21	2·19	1·203	1·10	2·557	2·515
1½	2·41	2·375	1·312	1·188	2·787	2·729
6	10·00	9·125	5·25	4·562	11·55	10·49

From the table the difference between the actual standard and the approximate but useful and much-used rule is readily seen.

Fig. 48.—A hexagon bolt-head is represented on a drawing by a three-face view, as a two-face view may easily be confused with the representation of

a square head. To prevent a one-face view of a square head being taken for a round head, it is usually crossed by diagonal lines. The distance across corners of a hexagon head is shown in fig. 48.

Example.—To set out correctly the hexagon head of a bolt 1 inch diameter.



FIGS. 46 and 47.

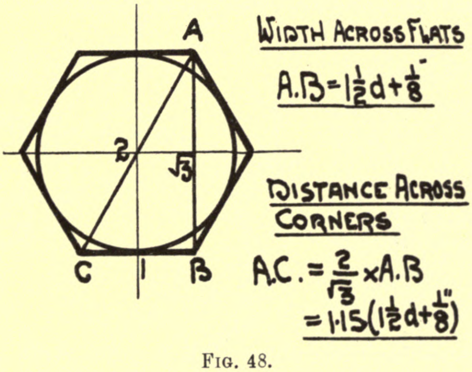


FIG. 48.

Fig. 49.—We have—

Width across flats $=1{\cdot}67$, say $1\frac{43}{64}$.
Thickness of bolt-head $=\ {\cdot}875$ or $\frac{7}{8}$.

Commence with a centre O, and draw a circle $1\frac{43}{64}$ inches diameter. Around this circle, with the 60° square, construct a hexagon. Draw in the bolt diameter dotted, thus completing the end elevation. For the side elevation, draw two parallel lines indicating thickness of bolt-head. Project the extreme points of the circle, R and S, giving M and N, the top of the nut. With the 45° set square, draw the chamfer NT and MU, the object of which is to remove the sharp corners. Draw the projections giving the side view of the face EF. The points W and X are determined by joining UT. The curves formed on

the flat sides of the nut by the chamfering off are then drawn in approximately by circular arcs as shown.

Note.—The head is chamfered off to avoid personal injury by contact with the sharp corners, also to improve the appearance of the work. As set out above, we still have a sharp point at Z. To remove this, the chamfer is often taken off a little more than indicated, in which case the circle RS becomes a construction line used to draw in the hexagon; the actual circle representing the top would be less than RS; the projection MN of the points U, W, X and the circular arcs would be modified.

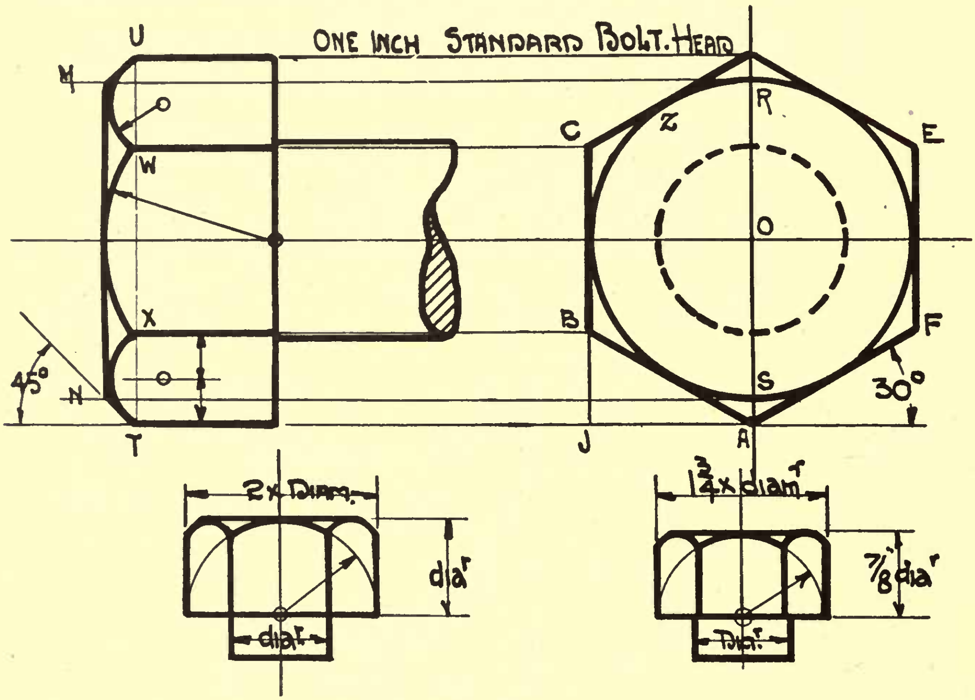


FIG. 49.

In all bolt-head and nut projections BJA is a 60° right-angle triangle; the base BJ is half the length of the side AB, that is, BC. **In the projected side elevation, each of the two outer faces has a width equal to half that of the middle face.**

Approximate Methods of setting out a Bolt-head.—To make the above construction to represent a bolt-head in every case would involve a serious waste of time; hence the approximate methods shown in fig. 49 are used. These are good enough, as the dimensions of a bolt-head are not put on the actual drawing, unless they are something special and not standard stock sizes. The two methods give:—

1. Width across corners = 2 × bolt diameter. Thickness of head = bolt diameter.
2. „ „ = 1·75 × „ „ „ = ·875 × bolt diameter.

For small-size bolts or nuts either of these two approximate rules must be

used with care, or sufficient clearances will not be obtained. Some idea of the discrepancy is shown by the following table:—

Bolt Diameter. Inches.	Distance across Corners.			
	From List.	Taken as $2 \times d$.	$1{\cdot}75 \times d$.	$1{\cdot}15\ (1{\cdot}5d + \frac{1}{8}'')$.
$\frac{1}{8}$ or ·125	·3902	$\frac{1}{4}$ or ·25	·219	36
$\frac{1}{4}$,, ·25	·6062	$\frac{1}{2}$,, ·50	·4375	·575
$\frac{1}{2}$,, ·5	1·0612	1 inch	·875	1·004
1	1·9284	2 inches	1·75	1·868

Bolt-holes.—When dimensioning a hole through which a bolt is to pass, the actual size of the hole required should be definitely stated. A mere note, such as, "Drill for $\frac{3}{4}$-inch bolt," "Core for $\frac{3}{4}$-inch bolt," etc., is insufficient. Bolts which are machined a fit are called fitting bolts, and the holes are drilled and reamed to size.

Nuts.—To form with the bolt-head two shoulders between which the loose pieces to be held together are clamped, a piece of metal is taken and a hole drilled or bored through it, the diameter of this hole being the same as the diameter at the bottom of the thread on the bolt. In this hole a screw thread is cut, of the same hand, pitch, and form of groove as the thread on the bolt. Hence the threads on the bolt fit into the threads in the nut, and by turning either the bolt or nut, and holding the other, the distance between the shoulders can be reduced.

Fig. 50 shows the end of a bolt screwed with a right-hand thread. The

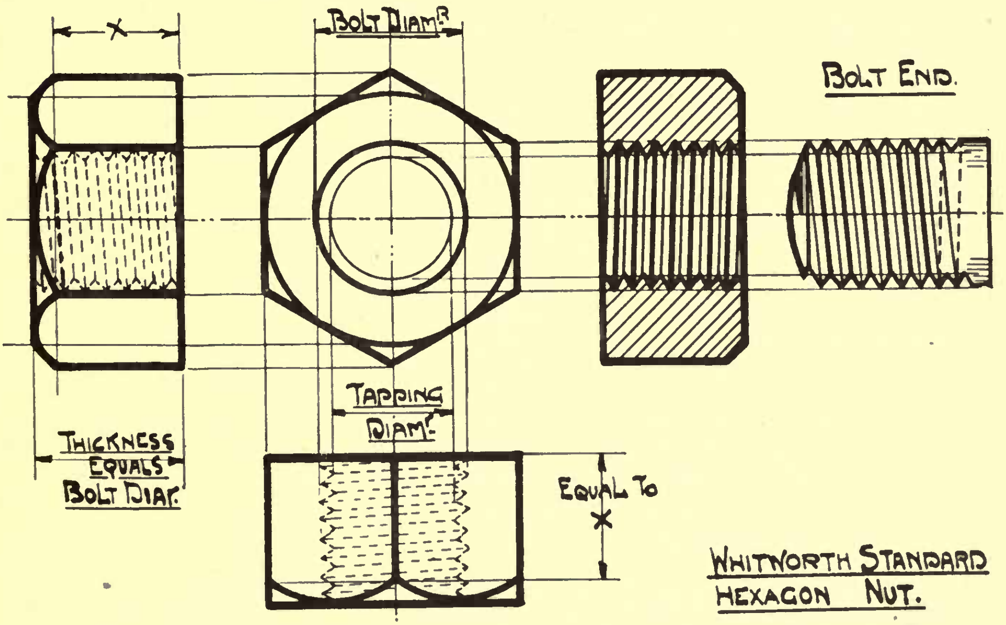


FIG. 50.

lines indicating the thread show the part on the front of the bolt; at the back the lines representing the thread will slope in the opposite direction, as shown dotted (also refer to fig. 35). If we draw a section through a nut, it is the part of the thread on the back of the bolt which fits into the grooves left in the nut; and for a nut in section, the lines indicating the top and bottom of the thread slope in a direction from left to right downwards. To be able to turn a nut easily, it is necessary that its dimensions, besides being sufficient safely to withstand the forces or loads which may come on it, be such that standard spanners can be used.

Standard Nuts (Whitworth).—The shapes mostly used are hexagon and square. The dimensions and method of drawing are exactly as for a standard bolt-head for the same size bolt, with the exception that—

Thickness of nut = Bolt diameter.

Fig. 50 shows three projected views and a section of a Whitworth standard nut suitable for a bolt ·75 inch diameter.

Washers.—Bolts and nuts are usually used in the rough, without any machining beyond screwing or tapping, and are spoken of as black bolts and nuts.

When a nut is screwed up against a rough, unlevel surface, the sharp bottom edges act as cutters, digging into the material and preventing the nut being drawn up tight. To form a bedding surface, a loose ring of metal called a washer is put under the nut against the face of the job. Again, for finished work, where bolts and nuts are turned and machined to size, the nut would cut into and deface the surface. In this case a turned washer is put under the nut. Sometimes both faces of a nut are chamfered to remove the cutting edges, but this produces an ugly finish.

Dimensions of Washers.

Bolt diameter.	$\frac{1}{4}$	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{7}{16}$	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{7}{8}$	1	$1\frac{1}{8}$	$1\frac{1}{4}$	$1\frac{3}{8}$	$1\frac{1}{2}$ inches.
Washer diameter.	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{7}{8}$	1	$1\frac{1}{8}$	$1\frac{3}{8}$	$1\frac{5}{8}$	$1\frac{7}{8}$	$2\frac{1}{8}$	$2\frac{3}{8}$	$2\frac{5}{8}$	$2\frac{7}{8}$	$3\frac{1}{8}$
Thickness gauge.	16	15	14	13	12	10	9	8	7	6	5	5	5
Thickness. Inches.	$\frac{1}{16}$	·075	·0875	$\frac{1}{10}$	·1125	$\frac{9}{64}$	$\frac{5}{32}$	$\frac{11}{64}$	$\frac{3}{16}$	$\frac{13}{64}$	$\frac{7}{32}$	$\frac{7}{32}$	$\frac{7}{32}$

1. Compare the diameter of the washer with the distance, across corners, of a standard hexagon bolt-head or nut.
2. Compare the above dimensions with the rules—

$$\text{Diameter of washer} = 2{\cdot}25 \times \text{bolt diameter.}$$
$$\text{Thickness} \quad " \quad = \tfrac{3}{20} \times \quad " \quad "$$

Tapped Holes.—The process of putting a screw thread inside a hole is called tapping. Very often it is not convenient to use a loose nut on the end of a bolt, in which case the bolt is screwed into a tapped hole and is called a **tap bolt.**

Size of Tap Drills (for Whitworth standard threads).—It will be noticed from the following table that the tap drill does not correspond exactly with the diameter at the bottom of the thread, being in nearly all cases slightly larger. The difference is called the clearance, and may vary with the class of work.

Diameter of Bolt Screw or Stud.	Threads per inch.	Diameter at Bottom of Thread.	Diameter of Drill.	Depth of Drilling.	Depth of Tapping.
$\frac{1}{4}$	20	·186	$\frac{13}{64}$	$\frac{1}{2}$	$\frac{3}{8}$
$\frac{3}{8}$	16	·295	$\frac{19}{64}$	$\frac{5}{8}$	$\frac{1}{2}$
$\frac{1}{2}$	12	·393	$\frac{25}{64}$	$\frac{13}{16}$	$\frac{5}{8}$
$\frac{5}{8}$	11	·508	$\frac{33}{64}$	1	$\frac{13}{16}$
$\frac{3}{4}$	10	·622	$\frac{5}{8}$	$1\frac{1}{8}$	$\frac{15}{16}$
$\frac{7}{8}$	9	·732	$\frac{47}{64}$	$1\frac{5}{16}$	$1\frac{1}{16}$
1	8	·840	$\frac{53}{64}$	$1\frac{7}{16}$	$1\frac{3}{16}$
$1\frac{1}{8}$	7	·942	$\frac{61}{64}$	$1\frac{5}{8}$	$1\frac{5}{16}$
$1\frac{1}{4}$	7	1·067	$1\frac{1}{16}$	$1\frac{7}{8}$	$1\frac{1}{2}$
$1\frac{1}{2}$	6	1·286	$1\frac{19}{64}$	$2\frac{1}{8}$	$1\frac{3}{4}$

Studs.—For some positions, such as cover-plates which must be removable, the use of a loose bolt and nut is objectionable. In other cases, such as an internal flange on a box or cylinder, the use of a loose bolt is not possible, as

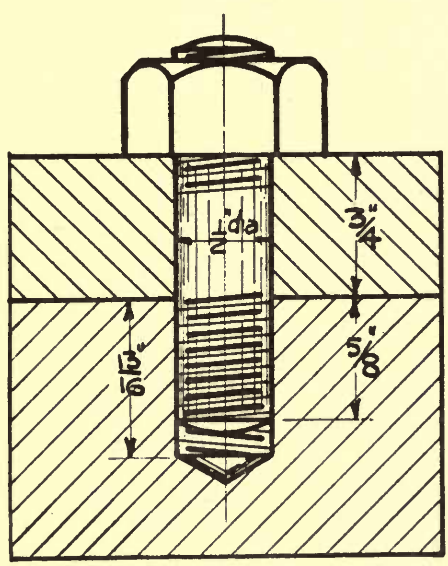
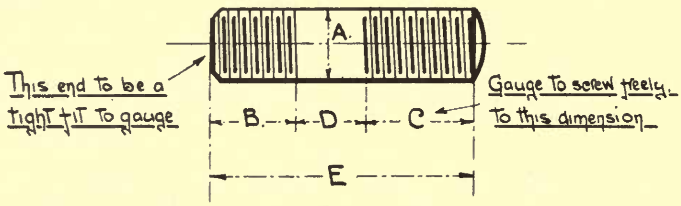


FIG. 51.

we cannot get at the under side to support it. Whenever a good tight joint is necessary, we then use a piece of plain bar screwed at both ends and called a **stud** (fig. 51). Dimensions of such are given in fig. 52. The chamfered

end is screwed tight into the tapped hole, binding itself against the dead end of the thread, but not reaching to the bottom of the hole. Sometimes the side of the stud is grooved to allow the air underneath to escape, to enable the stud to be screwed hard in.



Dimensions of Standard Steel Studs

A	½"	⅝"	¾"	⅞"	1"	1⅛"	1¼"
B.	⅝"	13/16"	15/16"	1 1/16"	1 3/16"	1 5/16"	1½"
C.	¾"	⅞"	1⅛"	1¼"	1½"	1¾"	2"
D.	½"	11/16"	11/16"	13/16"	13/16"	13/16"	1"
E	1⅞"	2⅜"	2¾"	3⅛"	3½"	3⅞"	4½"

Fig. 52.

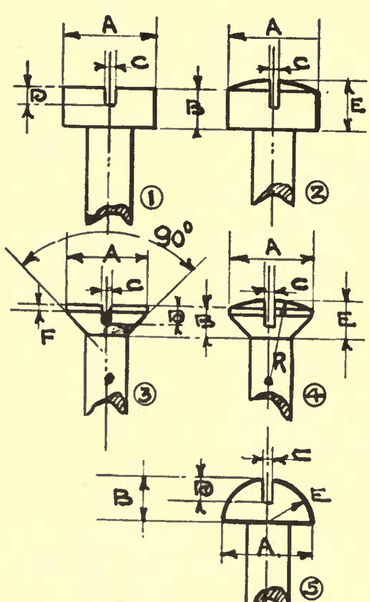


Fig	A	B	C	D	E	F
1	15/32"	·188"	·048"	·094"	-	-
2	"	"	"	"	·235	-
3	13/32"	–	·040	·082	–	·023
4	"	–	"	"	R=·470	"
5	15/32"	·234	·048	·112	·234	–

Fig. 53.—Table of Dimensions for Size O, B.A. Screw-heads.

Set Screw.—A set screw is a bolt in which the screwing is carried right up to the under side of the head. The head may be standard hexagon or square. For a square head, the thickness of head and side of head both equal screw diameter.

B.A. Screw Heads are usually slit to receive the screw-driver, and we have (fig. 53) cheese head, round cheese head, flat or countersunk head, round countersunk head, and button head. The dimensions for the heads suitable for 0 B.A. screws are given. Whitworth screws larger than $\frac{5}{16}$ inch diameter should not be arranged for the use of a screw-driver, unless for some special reason or purpose.

Steady Pins.—Whenever two details which require to have definite relative positions are held together by bolts and nuts, some definite register must be provided, as there must always be a certain amount of clearance between the bolts and the bolt-holes. When the details are in exact position, **pin-holes** (usually two in number) are drilled and reamed out. Pins fitting and driven tight into these holes in both details are used. Whenever the details are taken apart, it is easy to get them back to their proper positions by driving in the steady pins before tightening up the bolts.

FIG. 54.—Steady Pin.

Fixing of Bolts.—When tightening up a nut and bolt it is necessary to prevent either one or the other from rotating. In an open position, one spanner on the bolt-head and one on the nut is sufficient. If the bolt-head is in a confined space which will not admit the end of a spanner, or is of such a form that a spanner will not hold it, a square neck fitting into a square hole, or the head itself square-fitting into a square hole, prevents it from turning. For finished or machined work, a small pin driven into a hole drilled in the side or head of the bolt, and fitting into a corresponding recess cut into the detail against which the head bears, prevents rotation.

Locking of Nuts (to prevent them working loose).—When a single nut (fig. 55) is screwed hard down it retains its position owing to—

1. Friction between the threads in the nut and on the bolt.
2. Friction on the face against which it is screwed.

This friction is the result of the stress produced in the bolt by tightening up. If the details held together are subjected to severe vibration, the distance between the bolt-head and nut may be increased by—

1. The bolt stretching under the shocks falling upon it.
2. The surfaces held together bedding down to each other.

If this occurs, the stress producing the frictional grip is relieved, the nut becomes loose, and the vibration slacks it back.

To prevent this, and the serious consequences which may follow, many devices are used.

Lock-Nuts.—A lock-nut is an extra nut (thickness half to two-thirds that of the ordinary nut) put on the bolt, and tightened against the face of the first nut, with the result that both nuts are jammed on the thread of the bolt, independent of any force exerted on, or reaction of, the pieces held together, the result being that, should the holding pressure be relieved, there is no tendency of the two nuts to move on the bolt.

Fig. 55.—In screwing up the nut, the face A bears against the face B, the nut reacts on its bearing surface, and the bolt is drawn up. In tightening up a lock-nut (fig. 56), the face C is held and D turned relative to it; the bolt is stretched or drawn further up until the faces E and F are in hard contact, as shown. Thus the whole load on the bolt is carried by the threads in the upper nut, which should be a nut of ordinary thickness. The lower nut serves

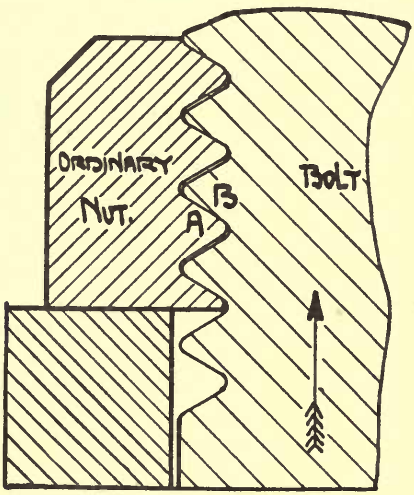


Fig. 55.

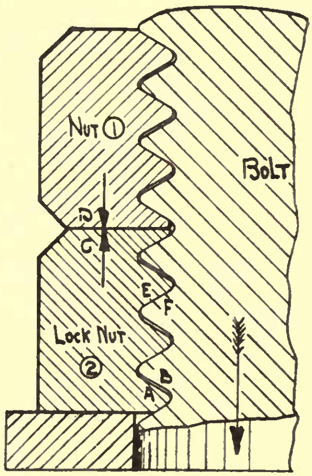


Fig. 56.

to jam with the top nut on the threads. Thus, should the load on the bolt be at all relieved, the pressure of nut (2) on its bearing face will be relieved; but the two nuts will move as a whole with the bolt end, and there is no tendency for either of them to become loose. The lower or jam-nut can be made thinner than the ordinary nut. For tightening up, this necessitates the use of a thin or lock-nut spanner, as the lower nut must be held while the top nut is turned to get them to the relative position indicated. The usual practice, owing to the special spanner difficulty, and for the sake of appearance, is to put the thin nut on top of the thick nut.

This is not correct practice, as all the load is carried by the top nut. The efficiency of the arrangement depends altogether on the jamming of the two nuts on the bolt thread, and if this is done in a proper way the arrangement is most satisfactory. For important work two standard nuts are used.

Spring Washer (fig. 57).—The use of a spring washer is another method adopted to prevent the nut slacking back. It consists of a piece of tempered steel coiled to form a portion of a helix. This is put on the bolt underneath

the nut. When tightening up the nut the washer is forced down flat. Should any elongation of the bolt take place, the washer springs out, still jamming the nut against the threads and preventing it from turning back. Also the sharp edges of the coil formed by the splitting dig into the metal of the nut and the bearing face, and form a further protection.

Many mechanical methods are used to prevent nuts subjected to vibration slacking back. There is quite a varied application of pins, cotters, and locking

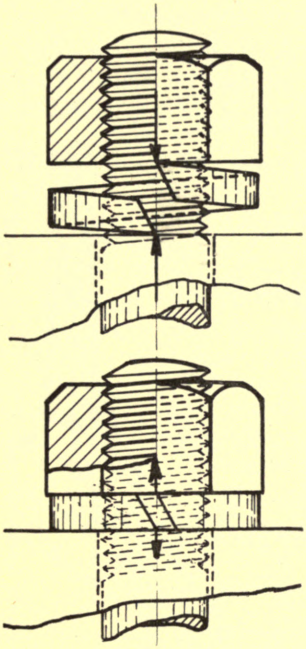


FIG. 57.

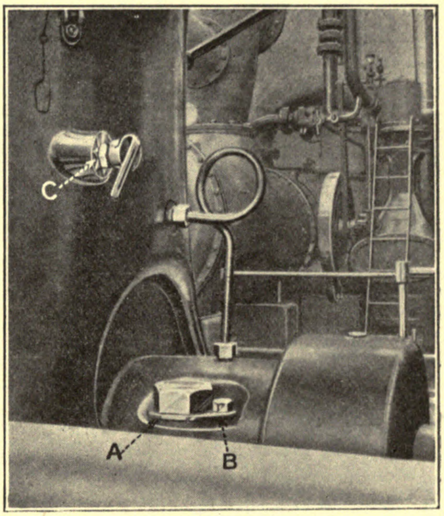


FIG. 58.—Locking Plate and Star Washer.

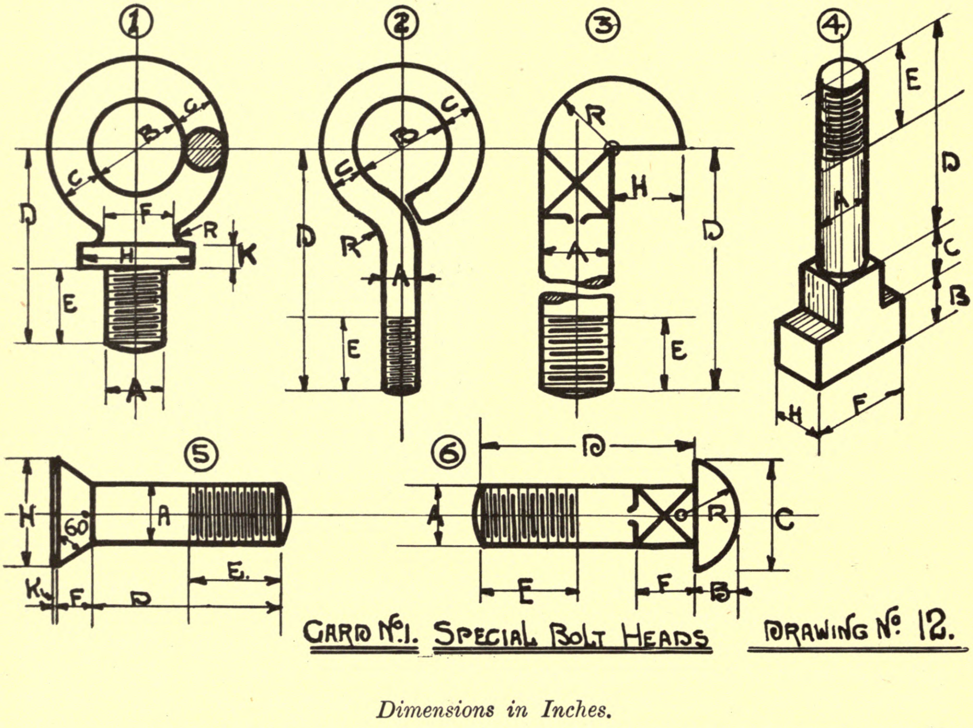
plates. The student should note the method adopted in any work which may come under his notice.

Fig. 58 shows one of the main bearing bolts of an engine. The locking plate A is cut out with two hexagons fitting closely the sides of the nut, thus locking the nut every twelfth part of a turn, and is held in position by the screw B. At C is a star washer locking the nut holding the indicating lever pin bush in the main column.

BOLTS AND NUTS.

Drawing No. 12.

Card No. 1.—From the dimensions given in the table, set out full size (and add, in correct projection, a view of the bolt looking on top of the bolt-head, representing hidden parts by dotted lines) a bolt of each type indicated.



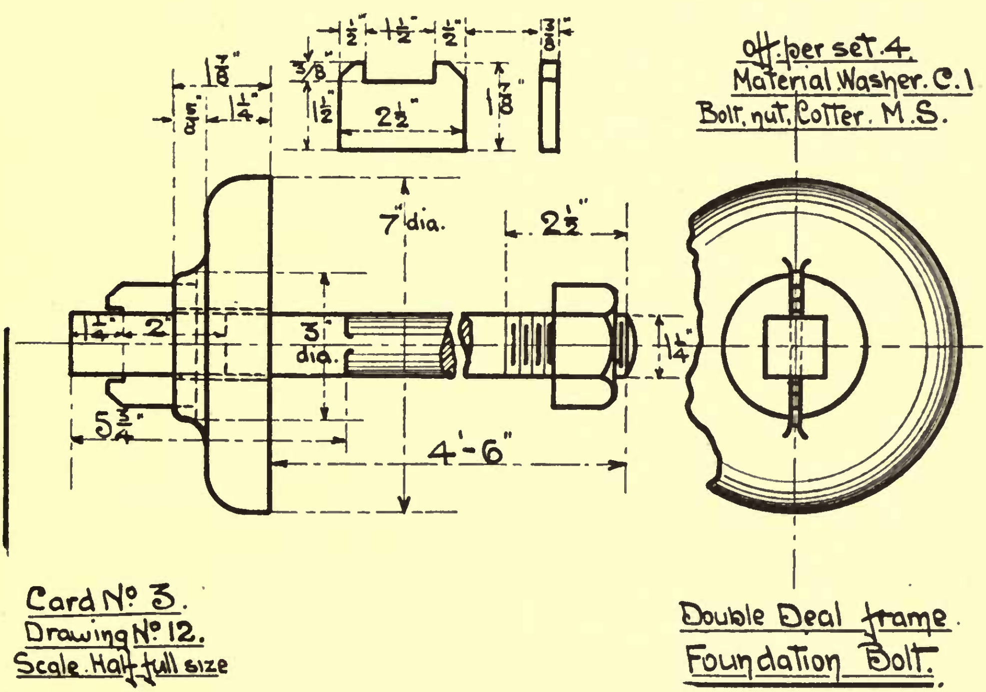
Dimensions in Inches.

Reference No.	A.	B.	C.	D.	E.	F.	H.	K.	R.
1	1	2	$\frac{5}{8}$	$3\frac{5}{16}$	$1\frac{1}{8}$	$1\frac{1}{16}$	$1\frac{1}{2}$	$\frac{5}{16}$	...
2	$\frac{3}{4}$	3	$\frac{3}{4}$	$25\frac{1}{4}$	$1\frac{1}{4}$	...	...	...	...
3	$\frac{3}{4}$	...	...	$3\frac{3}{4}$	$1\frac{1}{2}$	...	$\frac{3}{4}$	...	$\frac{3}{4}$
4	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	2	$\frac{3}{4}$	1	$\frac{1}{2}$	...	...
5	$\frac{5}{8}$	...	...	2	1	$\frac{3}{8}$	$1\frac{1}{8}$	$\frac{1}{32}$	...
6	$\frac{5}{8}$	$\frac{1}{2}$	$1\frac{1}{8}$	$2\frac{1}{4}$	1	$\frac{1}{2}$	...	...	...

Ref. 1. Lifting eye bolt: is fixed permanently into a machine such as an electric motor, to enable it to be readily lifted.
„ 2. Lifting eye bolt of cheaper form. Its use is of a more temporary character, such as screwing into pieces of machinery, for lifting into position during erection.
„ 3. Hook bolt, used for fixing machinery, such as shafting, to girders.
„ 4. Tee-head bolt, used for fixing details to the planed bed or table of a machine tool.
„ 5. Countersunk head bolt or screw. The head is sunk into the body of the detail, and is used where a projecting head on the surface is objectionable, as in fixing a sunk key in a shaft.
„ 6. Cup-head bolt, used to avoid rough projections, where the use of a hexagon head would look clumsy, as in fixing wood to ironwork.

Card No. 2.—Draw to a scale of twice full size a $\frac{3}{4}$-inch standard Whitworth hexagon nut, with bolt end to suit. Diameter of bolt, $\frac{3}{4}$ inch; diameter of drilled hole before tapping, $\frac{5}{8}$ inch; number of threads per inch, 10; width across flats, 1·3 inches. Refer to fig. 50.

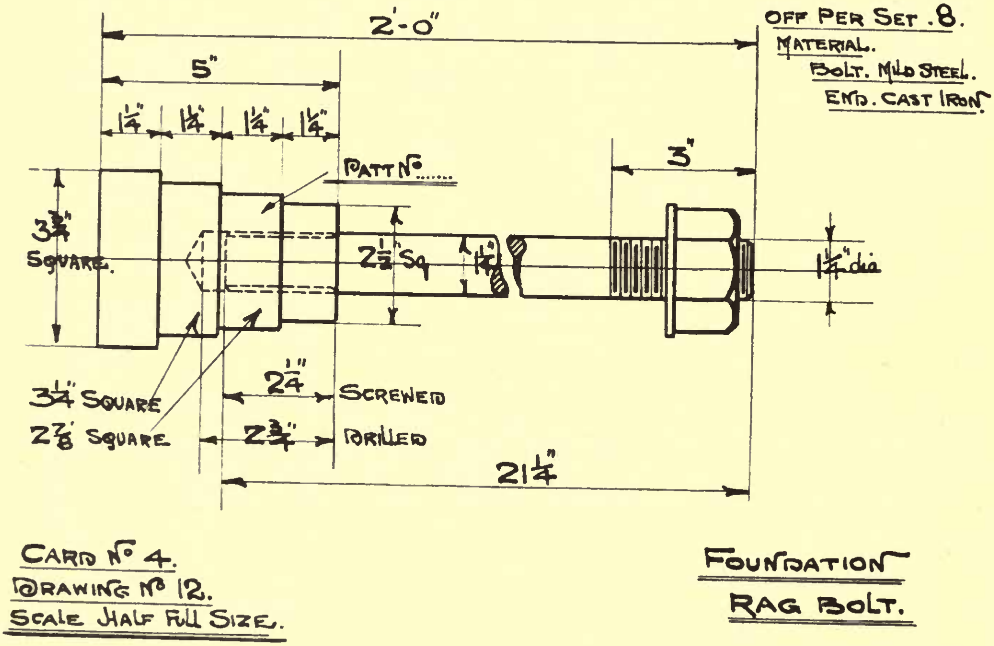
Card No. 3. *Foundation Bolt.*—The system of forces acting on, or within, most machines can be reduced to a single resultant force tending to produce motion in some direction, or to a couple tending to produce rotation. For this reason most machines must be anchored to a foundation of sufficient weight to prevent excessive vibration taking place. The cotter foundation bolt is used for heavy built-up foundations consisting of top course of heavy blocks of stone, body part built up of brick or concrete, lower courses of stone blocks.



Holes are left in the required positions for the bolts by building in, during construction, either square tubes roughly made in wood or ordinary rain-water drain-pipes. The bolts are dropped into position from the top after the bed has set, and are prevented from drawing out by the washer plate and cotter, which are put in from hand-holes constructed in the bottom courses of the foundation bed.

FIG. 59.—Rag Bolt.

Card No. 4.—Fig. 59 shows a rag bolt of a cheap and satisfactory type, consisting of a bar screwed at both ends. One end carries the retaining nut and washer; the other end is screwed into a cast-iron block, so that it jams hard up on the blind thread at the top of the screwed portion. To fix the bolt in position ready to take the machine, a wood frame templet is constructed from the drawings, with the holes bored in, and the bolts hung from it in their correct positions. The concrete foundation is then rammed in, and after it has set the wood templet is removed, and the bolts are in position ready for the machine. The top surface of cement is then put on, and the machine bed grouted after screwing it down in position.



Examples—

1. What is meant by the terms "taper," "second," "plug," and "master tap"? Explain how, and for what purpose, each is used.
2. Sketch (1) an inside and (2) an outside chaser, and explain how each is used.

3. Examine, make sketches and notes of a set of stocks and dies suitable for Whitworth thread, sizes $\frac{1}{2}$ inch to 1 inch, by eighths.
4. Show by a sketch how a ratchet drill is used to drill holes in awkward positions.
5. Under what circumstances is it necessary to use a box spanner?
6. Make fully dimensioned sketches of the detail parts of an adjustable spanner (monkey wrench).
7. Round nuts are screwed up by the aid of slots round the rim. Sketch, with dimensions, a spanner suitable for tightening up such nuts, which are 3 inches outside diameter.
8. For lifting masonry into position a bolt with a loose wedge, called a Lewis bolt, is used. Sketch complete with lifting eye, and all dimensions, such a bolt 1 inch diameter.
9. Make a rough sketch showing the foundation bed of a large stationary engine, and fill in leading dimensions.
10. In the bolt, Card No. 3, Drawing No. 12, compare (1) the area of the body part of the bolt with (2) area at the bottom of the thread at screwed end; (3) area of the square end slotted $\frac{3}{8}$ inch wide to take the cotter.
11. Describe, with sketches, how a star washer is used to prevent a nut slacking back. How is the washer held in place, and how is it prevented from rattling?
12. If cast-iron weighs 0·26 lb. per cubic inch, estimate roughly the weight of the cast-iron on the end of the detail, Card No. 4, Drawing No. 12.
13. Make a rough dimensioned sketch of a coach screw, and explain its use.
14. Wood screws: the heads may be countersunk or rounded, the diameter of the head being twice the diameter of the screw, the length for round-head screws being measured from under the head. The important dimensions are the gauge and the length. Plot a curve showing the relation between the gauge diameter and the diameter measured in inches.

Gauge.	00	0	1	2	3	4	5	6	7	8	9
Screw Diameter. Inches.	·060	·063	·066	·080	·094	·108	·122	·136	·150	·164	·178

The standard lengths are from $\frac{3}{16}$ inch to $2\frac{1}{2}$ inches.

COUPLINGS.

Drawing No. 13.

How to distribute energy from the source of supply to the various machines which are to be driven, is a most important question, and many methods are adopted. Thus we have :—

Shafting with belt, rope, or chain driving.
Compressed air, distributed through pipes.
Water under pressure, distributed through pipes.
Electrical distribution, using cables.

Where many machines are grouped together, as in workshop and factory, **line shafting** is usually employed. A long shaft is driven in the middle or at one end, and drives the machines through belts, running on pulleys at various points along its length. The shaft is built up from several lengths, and some method of fixing these lengths together is required. **Couplings** of different forms are used. The essential requirements, after considerations of strength have been satisfied, are :—(1) There shall be no projecting parts liable to catch a person's clothing—that is, they should have a perfectly smooth exterior surface; to obtain this, rim flanges are used. (2) When near a pulley carrying a belt, the plate shall be made solid with the external flanges, and the bolt-heads and nuts sunk into recesses and tightened up by means of a box spanner, so that, should the belt fall off the pulley, there is no danger of the projections on the coupling taking hold of it and causing damage. Considerations of first cost often cause these requirements to be overlooked.

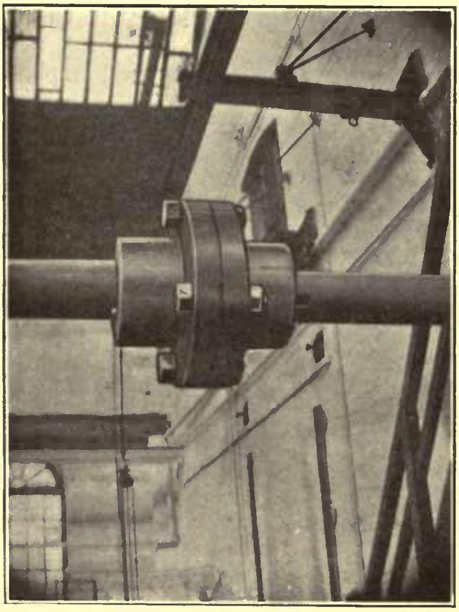
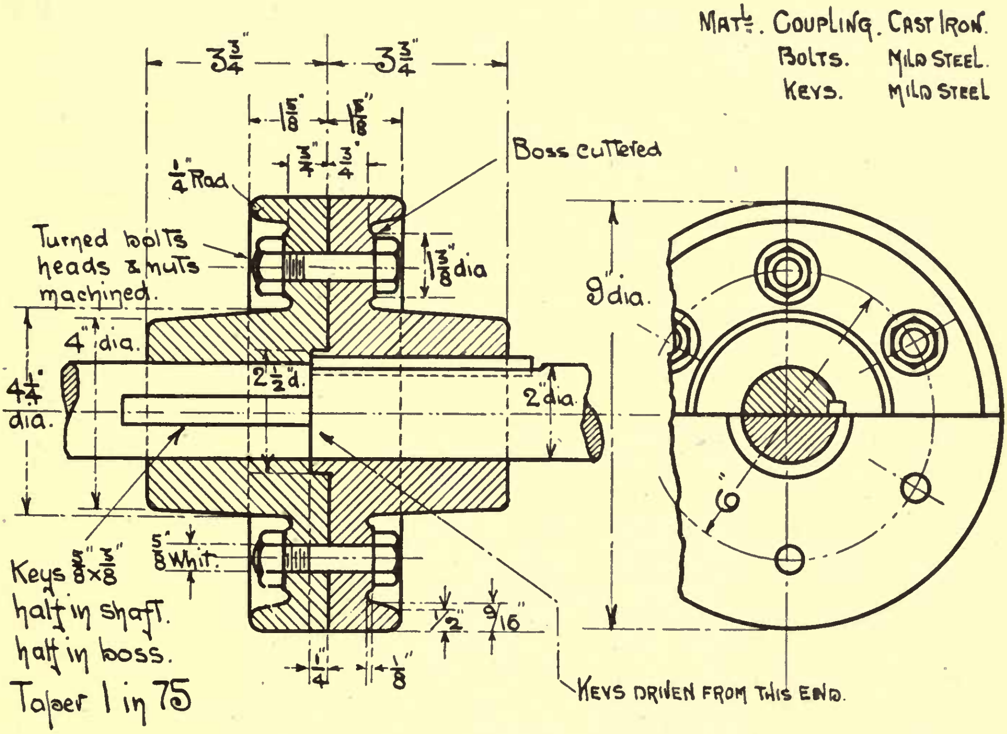


FIG. 60.—Line Shaft Coupling.

Fig. 60 shows the type of coupling in which the projecting bolt-heads and nuts are not in any way protected.

Drawing No. 13.—The shafting is registered, that is, got into exact alignment by means of the centering boss and recess indicated. The external flange is used to shield or guard the bolt-heads and nuts. Each half of the coupling is



DRAWING No. 13.
SCALE. HALF FULL SIZE.

FLANGE COUPLING.
FOR 2" DIA SHAFT.

keyed in position on its shaft before the shaft is assembled in position, and the keys are driven in from the faces which butt together. Do not draw the coupling as shown, but—

Draw to a scale of half full size a similar coupling to the following dimensions:—

Shaft, 4 inches diameter. Keys, $1\frac{1}{8}$ inches wide × $\frac{13}{16}$ inch thick, half in shaft, half in boss.
Each boss 8 inches diameter, $5\frac{1}{2}$ inches through. Register, $5\frac{1}{2}$ inches diameter × $\frac{3}{8}$ inch projection. Bolt circle, 11 inches diameter.
Plate, $1\frac{1}{2}$ inches thick. Eight bolts, each $\frac{7}{8}$ inch diameter.
Each flange $2\frac{3}{4}$ inches wide by $\frac{1}{2}$ inch thick. Outside diameter, 15 inches.

Draw a sectional elevation, an end view half looking at the outside, half looking at the joint face, and add a plan. Fully dimension the drawing made.

The strength of a shaft to resist torsion only is given by the formula

$$\text{Twisting moment} = \frac{\pi}{16} \cdot f \cdot \text{diameter}^3,$$

where f is the stress produced per unit area of cross section. For mild steel, the working value is taken as 10,000 lbs. per square inch.

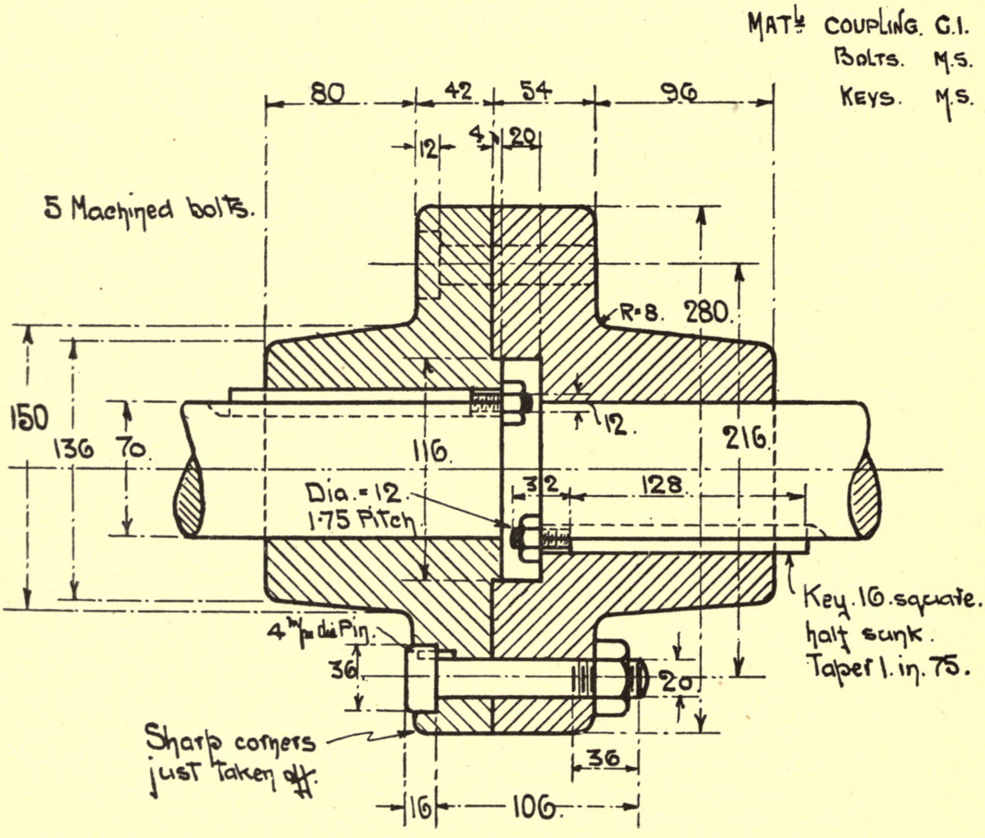
In terms of the horse-power, H.P., transmitted,

$$\text{Twisting moment} = \frac{63{,}000 \, . \, \text{H.P.}}{\text{N}} \text{ inch-lbs.},$$

where N is the number of revolutions per minute of the shaft.

Thus
$$\frac{\pi}{16} \cdot f \cdot d^3 = \frac{63{,}000 \, . \, \text{H.P.}}{\text{N}}$$

$$\text{H.P.} = \frac{\pi \cdot f \cdot d^3 \, . \, \text{N}}{16 \times 63{,}000};$$



DRAWING No. 13.A.
SCALE HALF FULL SIZE.

FLANGE COUPLING.
FOR MOTOR-GENERATOR.

From this we see that the power transmitted is proportioned to the speed and the cube of the diameter.

The formula enables the diameter of a shaft to be calculated, to transmit a given H.P., considering torsion only. Practically, many other points have to be considered in fixing the diameter of a shaft, such as bending due to the weight of the shaft itself, pull of the belts running from it, bending due to the weight of the pulleys carried, stiffness to prevent one end of the shaft oscillating relatively to the other, etc.

Example.—Taking f as 10,000 lbs. per square inch, what diameter of line shaft is required to transmit 20 H.P. at 300 revs. per minute?

Using above formula,

$$d^3 = \frac{20 \times 16 \times 63{,}000}{\pi \times 10{,}000 \times 300} = 2{\cdot}13. \qquad \text{Diameter} = 1{\cdot}28 \text{ inches.}$$

The actual shaft (refer to Drawing No. 13) is 2 inches diameter, so that, to allow for the considerations given, the diameter obtained by calculation has been multiplied by $\frac{2}{1{\cdot}28}$, or 1·56.

Drawing No. 13A.—The coupling shown is used for connecting a motor to a generator, both mounted on the same base-plate. The method of putting

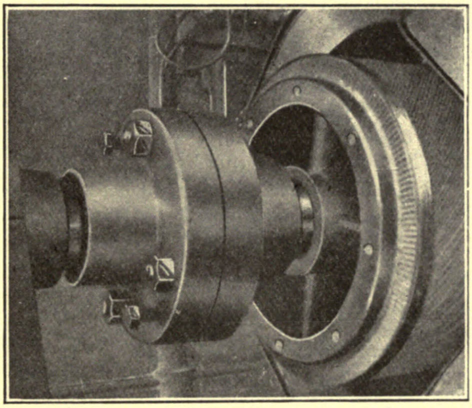


FIG. 61.—Machine Coupling.

in the key, then the half-coupling on the shaft, and tightening up the key, is readily seen.

Draw to a scale of half full size the section shown, project an outside end elevation, and add a plan. All dimensions given are in millimetres.

Example.—This coupling connects two shafts, each carried in two bearings, each shaft having a heavy armature mounted in between. It transmits 27 kilowatts at 890 revs. per minute. Show that a multiplying constant of 2·64 has been used in determining the diameter of the shaft.

1 kilowatt = 1000 watts, and 746 watts = 1 H.P., that is, work done at the rate of 33,000 foot-lbs. per minute.

Example.—For the coupling, Drawing No. 13A, compare the strength of the bolts with the strength of the solid shaft, as regards direct shearing only.

Assuming they are made out of the same material, and allowing the same values for f, the working stress in the material, we have:

Twisting moment on shaft $= \frac{\pi}{16} . f . d^3$. Also the moment of the resistance offered by bolts = bolt area × number of bolts × f × radius of bolt circle.

$$\therefore \frac{\text{Strength of bolts}}{\text{Strength of shaft}} = \frac{\frac{\pi}{4} . b^2 . \mathrm{N} . f . r}{\frac{\pi}{16} . f . d^3} = \frac{\frac{\pi}{4} \times 20^2 \times 5 \times f \times 108}{\frac{\pi}{16} \times f \times 70 \times 70 \times 70} = 2{\cdot}5.$$

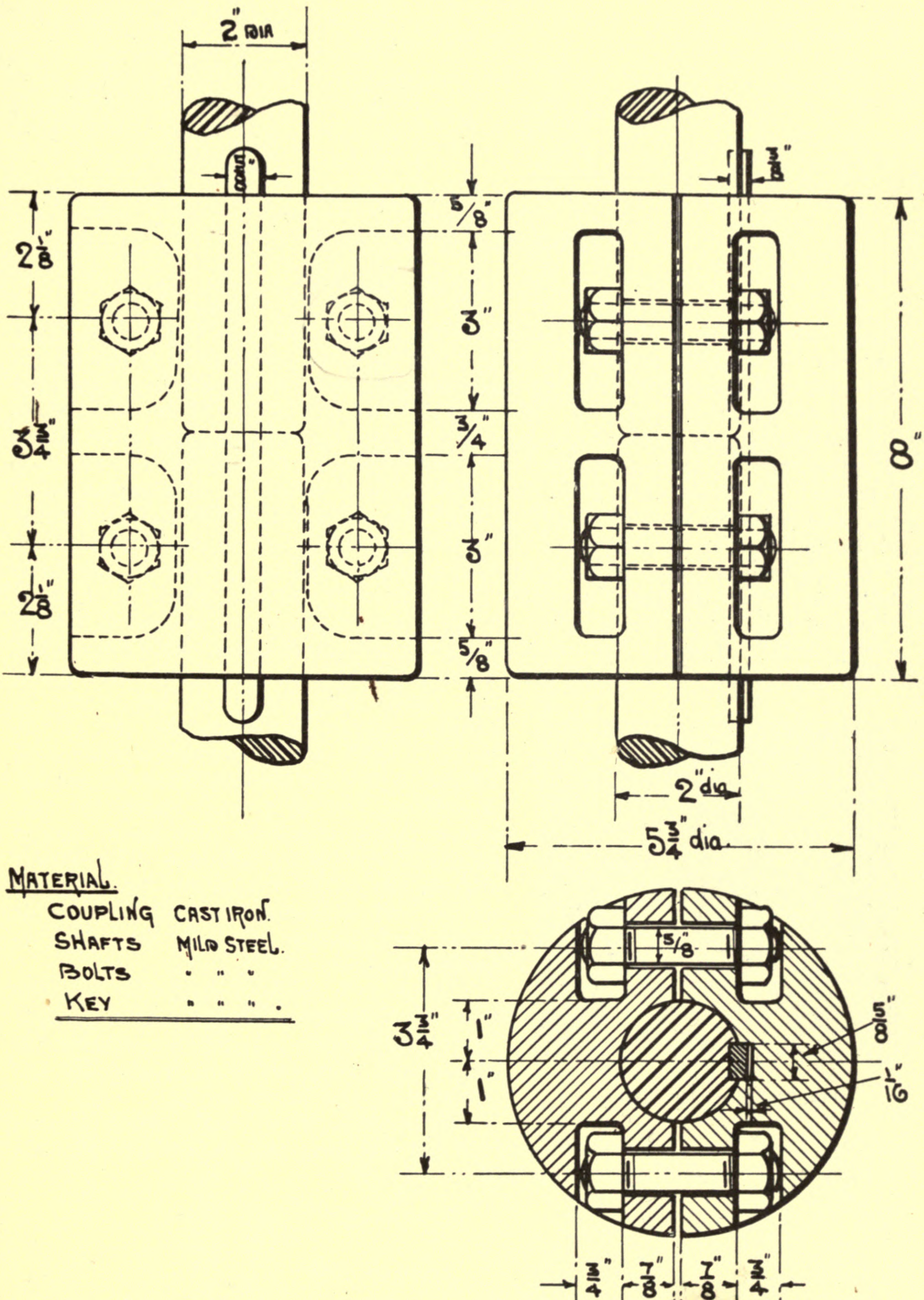
Example.—Show that in the coupling, Drawing No. 13, for direct shearing, the strength of the bolts is 3·5 times the strength of the shaft.

Drawing No. 13B.—Split muff coupling: may be used when pinched for room. If made solid, since the key for either shaft is driven from the opposite end, there must be sufficient end clearance to drive and withdraw the keys, otherwise the coupling is split as shown. The coupling may drive one shaft from the other by friction alone, or a key fitting on the sides only may be used, the top clearance allowing the two halves to be drawn together to grip the shaft tightly.

Draw to full size the front elevation shown; a plan with the top half of the coupling removed; an outside end elevation.

Example.—The slots for the nuts are cored out and left rough, but the coupling is otherwise machined all over. Describe the way in which the machining process is carried out.

Example.—Make a drawing of a solid muff coupling, suitable for connecting up two shafts each 2 inches diameter. Fully dimension, and indicate clearly the keyways in each shaft, and the direction of the taper of the keys.



DRAWING No. 13. B.

SCALE FULL SIZE.

SPLIT MUFF COUPLING

FLEXIBLE COUPLING.

Drawing No. 13c.

As in line shafting, the two shafts being end on, one shaft is driven from another by the solid coupling bolting them together, and care is taken to get the axes of the shafts in line. In other cases, such as a motor driving a machine direct, both have the axes of their shafts fixed relative to their other parts by the bearings, to get them in one and the same straight line, the only means of adjustment being to pack the base of either on its foundation. If the two machines are on the same solid base-plate this is easy. If on separate bases and connected by a solid coupling, imperfect alignment will lead to trouble and rapid wear in the bearings. A continuous-current motor shaft usually has about $\frac{1}{16}$ inch end play to prevent the brushes wearing grooves in the commutator, while the machine shaft has practically no end play. A flexible coupling relieves the shafts and bearings from strains due to imperfect fixing, and permits end play. The coupling shown consists of a face-plate key on the end of the motor shaft. Four pins equally pitched are forced into this plate, the back ends being riveted over. A similar plate is keyed on the end of the machine shaft, and carries four similar pins, but at a different radius from the centre. A leather belt is passed round the two sets of pins, and the joint laced up by means of an ordinary belt-lace. The leather also serves as an insulation between the motor and the machine, and in case of motor breakdown prevents the machine becoming alive.

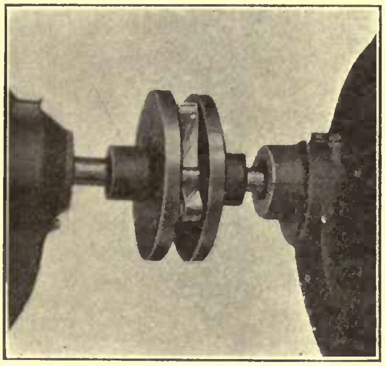
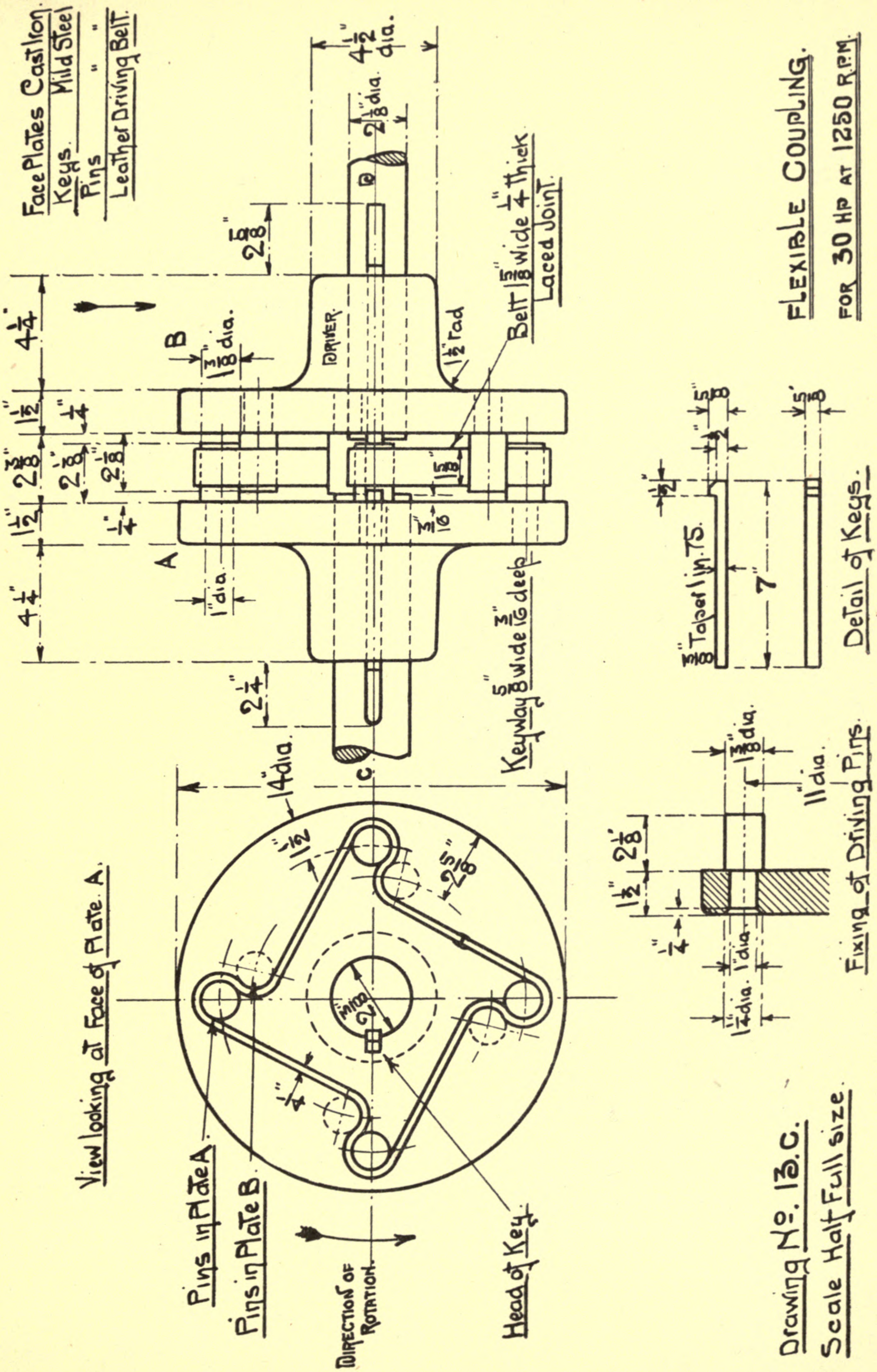


Fig. 62.—Flexible Coupling.

Draw to a scale of half full size the two views shown. Project a section made by the horizontal plane CD, assuming the upper half removed and looking in the direction of the arrow shown.

Example.—Show that, when transmitting 30 H.P. at 1250 revolutions per minute, each pin on the driver exerts a force of 86 lbs. on the coupling belt.


Face Plates Cast Iron.
Keys Mild Steel
Pins " "
Leather Driving Belt.
FLEXIBLE COUPLING.
FOR 30 HP AT 1250 R.P.M.
DRIVER.
Belt 1 5/8" wide 1/4" thick
Laced Joint.
Keyway 5/8" wide 3/16 deep
Taper 1 in 75.
Detail of Keys.
Fixing of Driving Pins.
View looking at Face of Plate A.
Pins in Plate A.
Pins in Plate B.
DIRECTION OF ROTATION.
Head of Key.
Drawing No. 13.C.
Scale Half Full size.

UNIVERSAL JOINT COUPLING.

Drawing No. 13D.

Fig. 63.—A coupling of this type is used to connect and drive one shaft from another, when their axes intersect and are inclined to each other. The drawing shows a double application. The axis of shaft B is fixed by its bearing, but the shaft can slide in or out. It drives the sleeve shaft, which in turn drives the shaft A. The arrangement is copied from a milling machine, and the table with shaft A can rise and fall, as well as travel crosswise.

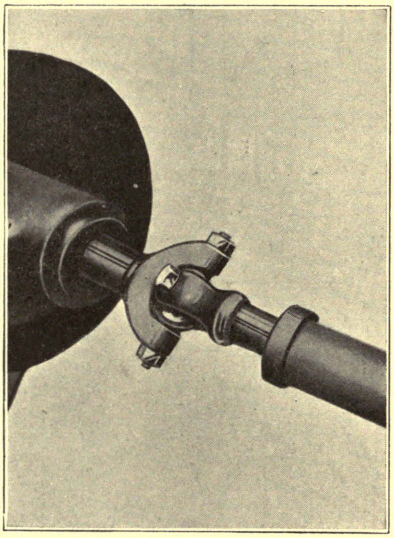
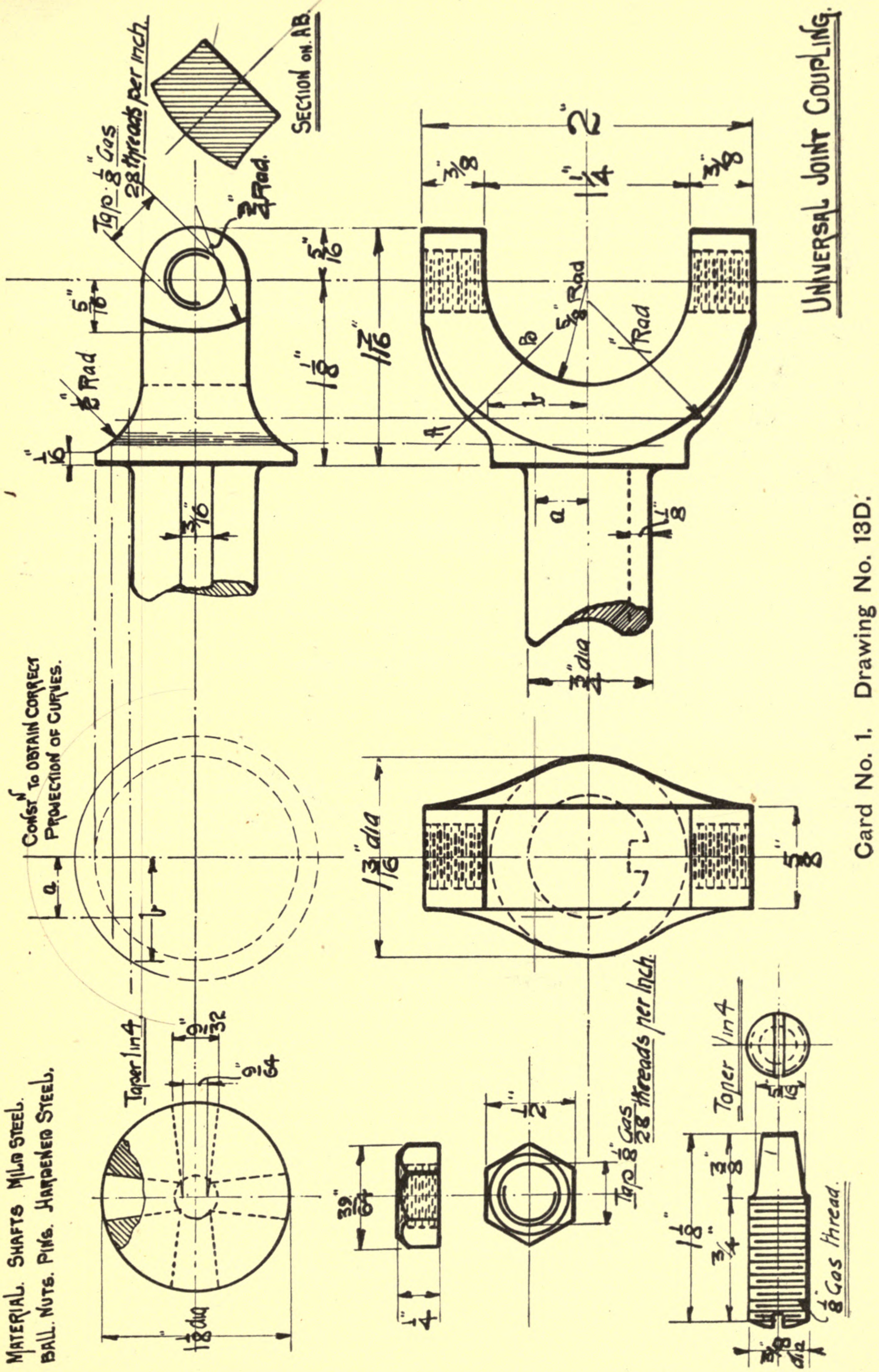


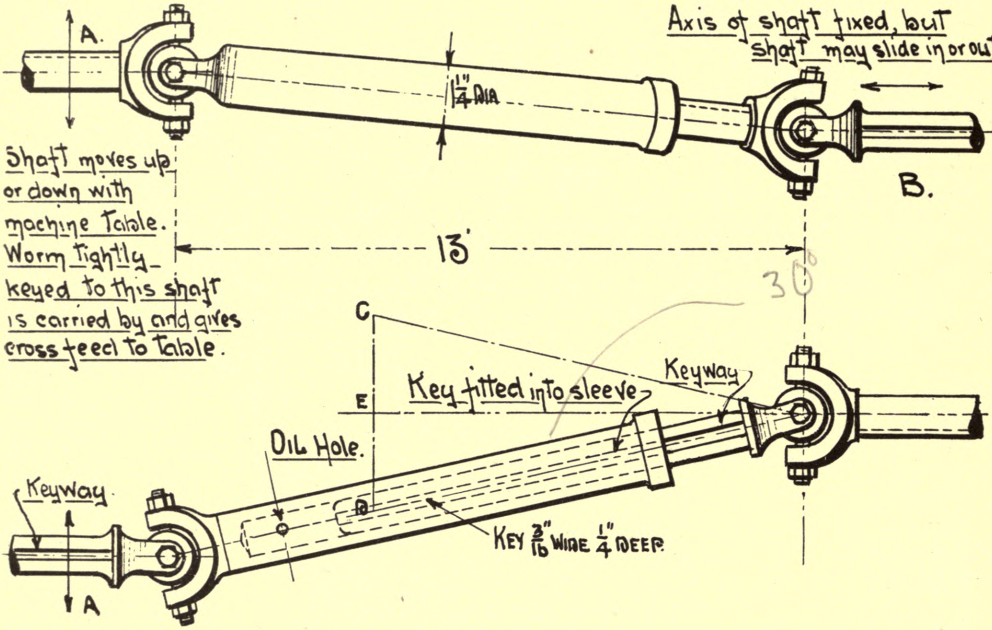
Fig. 63.—Universal Joint Coupling.

In plan only, take one position, shaft B free to rotate only, and assume sleeve shaft rigidly fixed to it. A rotation of the sleeve shaft would sweep out a cone base CD. Now introduce the universal joint. The sleeve can swing horizontally on the vertical pins in the ball, and vertically on the horizontal pins. Consider half a revolution of shaft B, sleeve shaft solid; D would go to C; with joint coupling it can be swung back to D. Consider a quarter revolution; D is up at E, a vertical motion down, and a horizontal motion brings it back to D.


UNIVERSAL JOINT COUPLING.
Card No. 1. Drawing No. 13D.
SECTION ON AB.
Tap 1/8" Gas 28 threads per inch.
CONST^N TO OBTAIN CORRECT PROJECTION OF CURVES.
MATERIAL. SHAFTS MILD STEEL.
BALL. NUTS. PINS. HARDENED STEEL.
Taper 1 in 4
1/8 Gas thread.

Thus the motion of the ball on its pins enables the sleeve shaft to rotate and maintain a fixed position.

Draw plan and elevation of the complete connection, details of the joint being given in Card No. 1.



DRAWING No. 13.D

SCALE. FULL SIZE.

UNIVERSAL JOINT COUPLING.

FOR MILLING MACHINE.

CLAW COUPLING OR CLUTCH.

Drawing No. 13E.

A CLAW coupling or clutch is used for rapidly connecting, also disconnecting, two shafts or details, particularly when the change has to be often made. A face-plate is attached to, or formed on, each shaft, and teeth formed on the face of one engage with teeth on the other when driving. When not driving, one is moved relative to the other, until the teeth come out of gear.

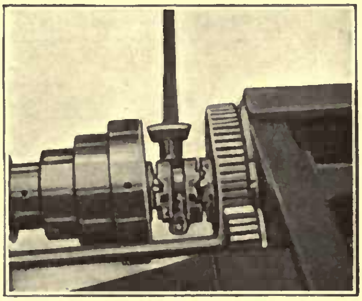


FIG. 64.—Claw Coupling.

The clutch in this example is used in connection with a boring machine. The horizontal shaft A is the driven shaft, and the double claw clutch is free to slide along it, but forced to rotate with it by the two feather keys, the ends of which fit into the loose rings indicated, and turn them with the shaft.

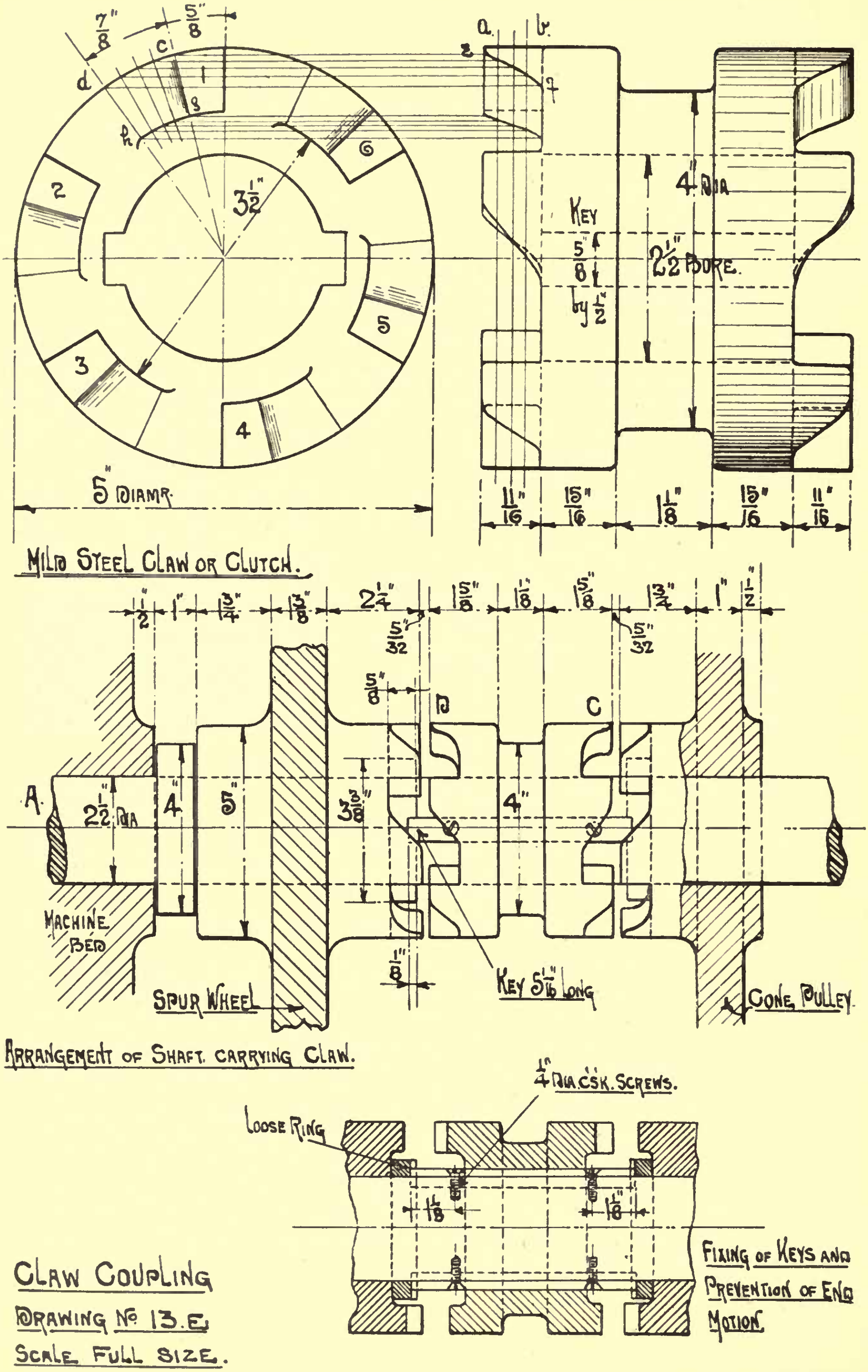
To obtain a range of speeds of the boring bar, the drive consists of cone pulley and back gear. For light work and quick speeds the cone pulley drives the shaft direct, and the face C of the claw engages with the claw on the face of the pulley. For heavy work and slower speeds the back gear is used; the claw is shipped over until the face D engages with the claw on the face of the spur-wheel.

Draw to a scale of full size the two views of the clutch shown, and add a plan.

To facilitate the teeth going into gear, also to give them strength, the backs are backed off, the shape of the tooth in side elevation being obtained thus:—

The distance *ab* is divided into four equal parts; *cd*, the backing off, is also divided into four equal parts. The intersection of the projection lines gives the form of the curve for the top of the tooth in side elevation. The teeth being radial, divide *gh* into four equal parts; the cross projections give the form of the curve representing the bottom of the tooth. The clearance between the teeth when in gear is readily seen by tracing the teeth on a piece of tracing paper, turning it over so as to show the two sets of teeth in gear.

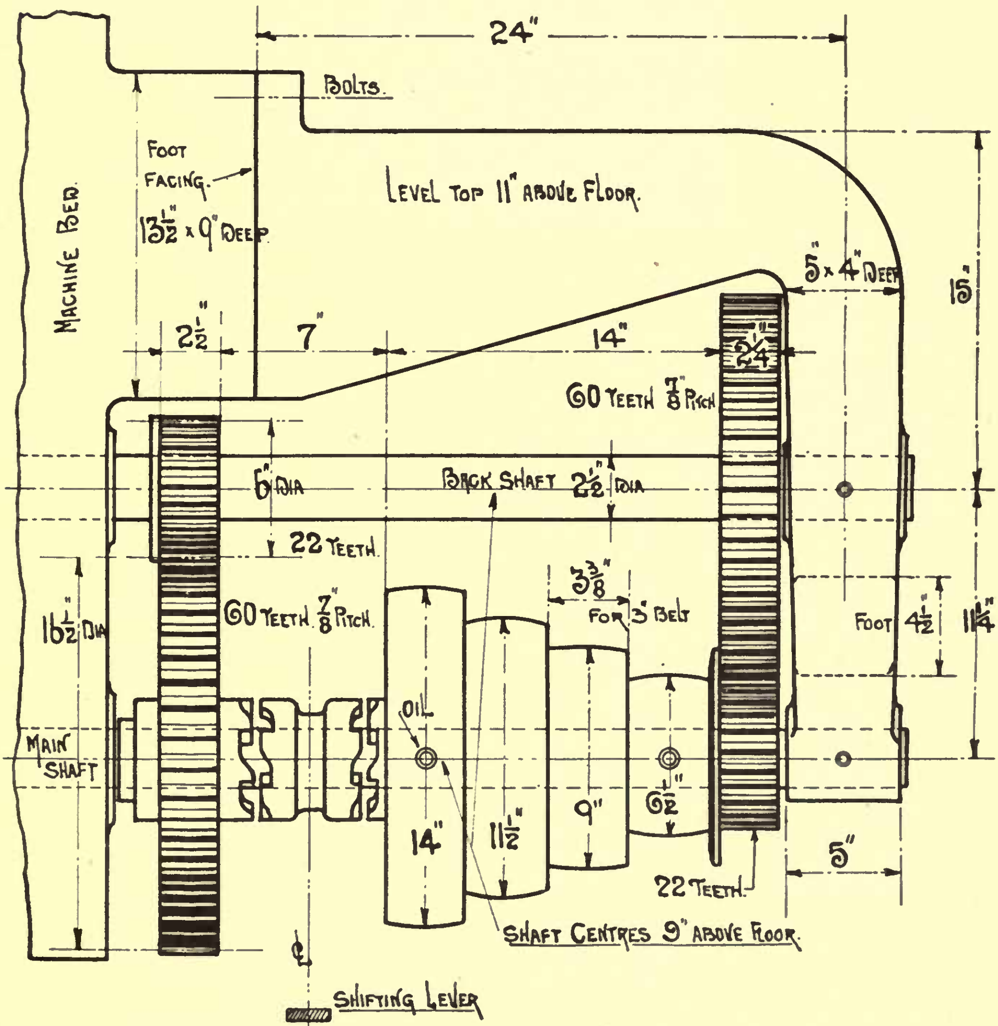
The middle view in 13E shows the arrangement of the claw on the shaft, and the lower view, the method of fixing the keys through which the claw drives the shaft, and of preventing end motion of the cone pulley and spur wheel, which run loose on the shaft.


5" DIAMR.
4" DIA.
KEY 5/8" by 1/2"
2 1/2" BORE.
MILD STEEL CLAW OR CLUTCH.
2 1/2" DIA
MACHINE BED
SPUR WHEEL
KEY 5 1/16" LONG
CONE PULLEY.
ARRANGEMENT OF SHAFT CARRYING CLAW.
1/4" DIA. CSK. SCREWS.
LOOSE RING
FIXING OF KEYS AND PREVENTION OF END MOTION.
CLAW COUPLING
DRAWING No. 13. E.
SCALE FULL SIZE.

Example.—Refer to Drawing No. 13E, 1. The countershaft makes 200 revolutions per minute, and carries an exactly similar cone to that on the machine. Make a list of the different speeds at which the machine main shaft can be driven.

Belt on pulley . .	A.	B.	C.	D.
Without back gear .				
With back gear . .				

Plot a curve to show how the speed varies on the eight drives which can be obtained.



Drawing No. 13. E. 1.

Arrangement of Driving Gear.

The arrangement of the shifting gear to drive the main shaft from either the cone pulley or through the back gear is shown in Drawing No. 13E, 2.

Draw to a scale of half full size separate detail drawings fully dimensioned and all necessary views of the bracket, clutch lever, shaft, and hand lever with spring poppet.

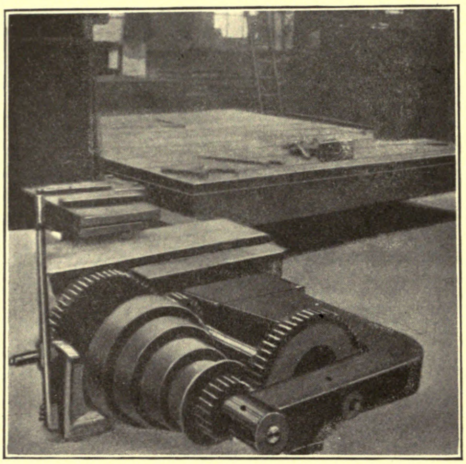
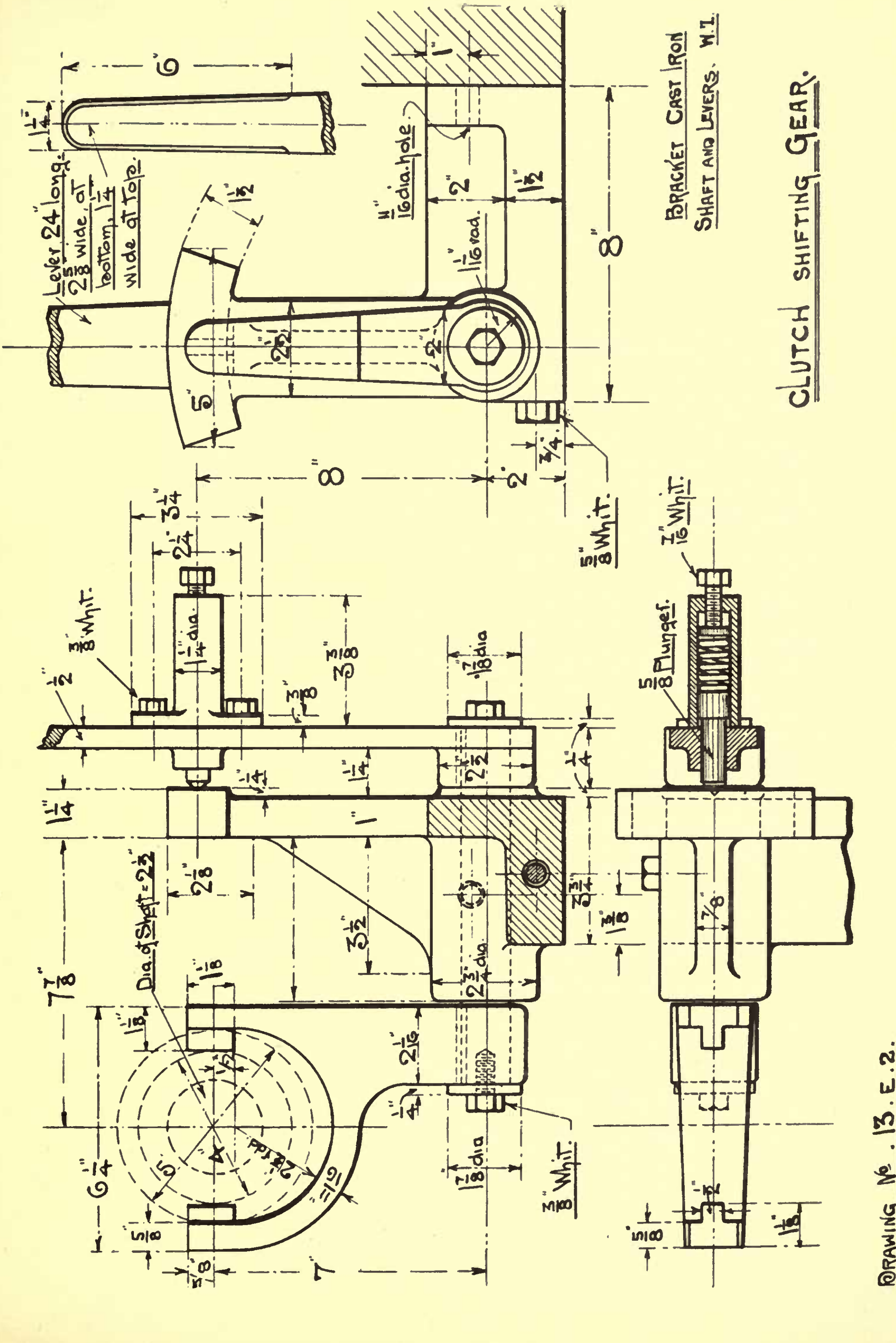


FIG. 65.—Application of Claw Coupling.

Example.—Make a drawing to a scale of quarter full size of the complete clutch and driving gear, giving plan, front and side elevations. For dimensions not given, obtain your own, making them something definite, and marking them off from the edge of the rule.

Fig. 65 affords some idea of what the arrangement is like, to assist the student in making this drawing.


CLUTCH SHIFTING GEAR.
BRACKET CAST IRON
SHAFT AND LEVERS. W.I.
DRAWING No. 13. E. 2.

KEYS.

THE foregoing examples will have shown the necessity of an arrangement for fixing details which are to rotate with a shaft, to that shaft.

The key is an auxiliary detail which transmits the effort from the shaft to the boss surrounding the shaft, and at the same time may hold the details securely together.

The usual types of key used are hollow, flat, and sunk.

Hollow-back Key.—When the energy to be transmitted is small, or the position of the detail fixed to the shaft need not be permanent, frictional grip between the boss and shaft is relied upon for the drive. After the boss has been placed in its proper position on the shaft, it is staked on tight and the necessary grip obtained by means of a metal wedge formed and fitting as shown in fig. 66.

Flat Key.—With the transmission of a greater effort, a more rigid construction is obtained by making the key rectangular in cross section, and forming a flat on the shaft. Here again the effort is transmitted largely by the frictional grip of the boss on the shaft.

Fixing of Keys.—When keying two details together, it is usual to place them in their correct relative positions, and then drive in the key. In confined positions the key is put in first and the detail then driven into position. To enable the key to be readily withdrawn, a projecting or gib head is fitted. A drawing should always indicate from which side the key is to be driven into the details.

Sunk Key.—For transmitting heavy loads, this form, which requires a flat bottom groove or slot cutting in the shaft, is always used. In addition to any frictional grip, the energy is transmitted through the key itself acting as a beam and transmitting the load from the shaft to the wheel boss.

Dimensions for Keys.—The load on a sunk key tends to cause it to fail—

1. By shearing: that is, the top half in the boss sliding relative to the lower half in the shaft as viewed in cross section.
2. By crushing of the material either of the key or the shaft.

The theoretical dimensions to make a key as strong as the shaft can be calculated, but it will be found that keys are made to more or less empirical rules obtained as the result of experience and varying with the class of work.

The student should therefore make out for future use tables somewhat as follows:—

1. Standard square keys sunk half depth in shaft. Side of key in inches equals one-quarter diameter of shaft in inches, stock sizes being $\frac{1}{4}$ inch, $\frac{5}{16}$ inch, $\frac{3}{8}$ inch, $\frac{7}{16}$ inch, $\frac{1}{2}$ inch, $\frac{5}{8}$ inch.

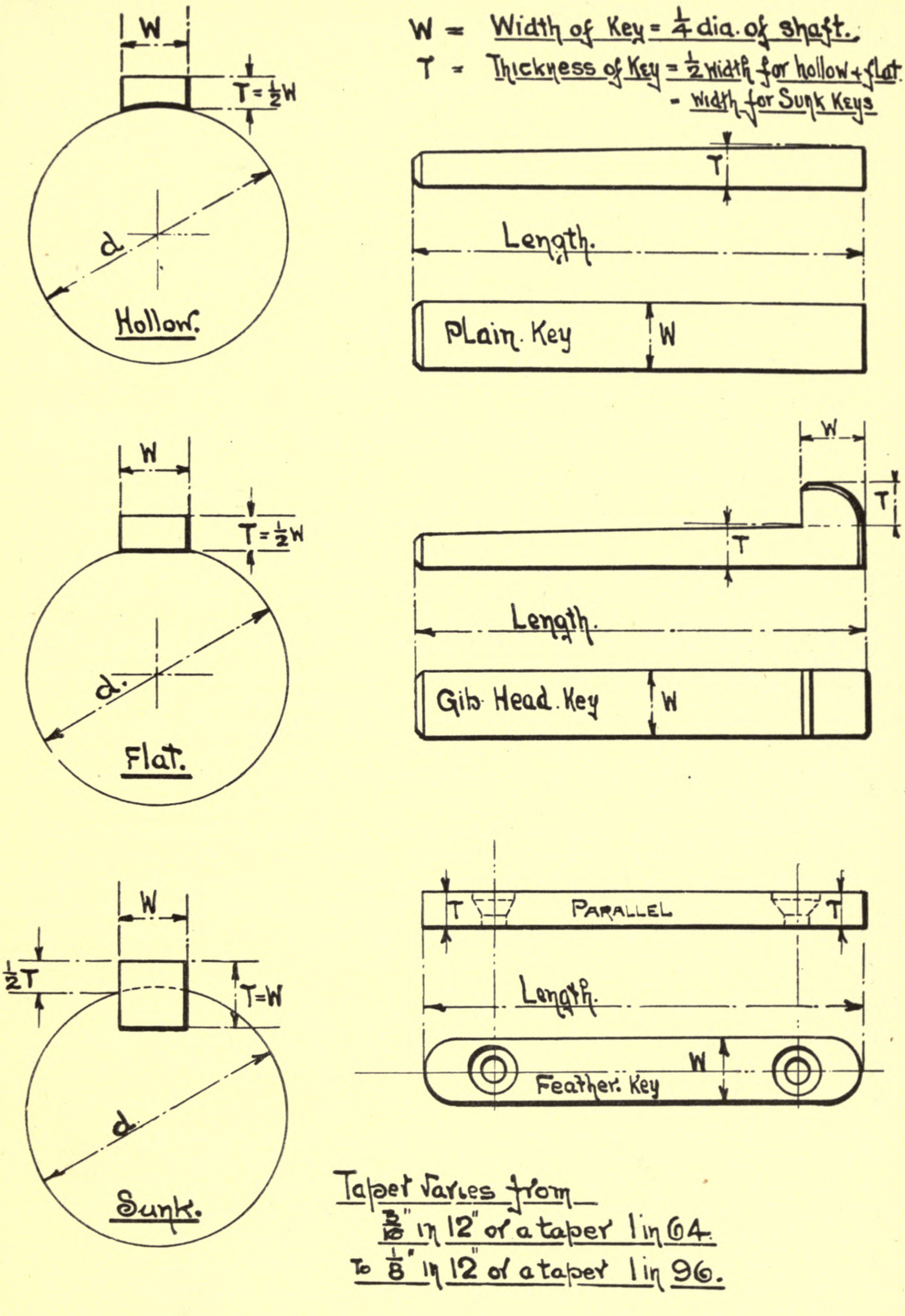


FIG. 66. DIMENSIONS OF KEYS.

2. Stock sizes of keys are, in inches—

Width . .	$\frac{1}{4}$	$\frac{5}{16}$ and $\frac{3}{8}$	$\frac{7}{16}$	$\frac{1}{2}$	$\frac{5}{8}$
Thickness .	$\frac{3}{16}$	$\frac{3}{16}$ $\frac{1}{4}$ $\frac{5}{16}$	$\frac{1}{4}$ $\frac{5}{16}$ $\frac{3}{8}$	$\frac{5}{16}$ $\frac{3}{8}$ $\frac{7}{16}$	$\frac{1}{2}$

Lengths from 1 inch to 5 inches, advancing by $\frac{1}{4}$ inch; taper, 1 in 48.

Examples—

1. In the coupling, Drawing No. 13B, compare the strength of the key with the strength of the solid shaft.

   Twisting moment on shaft $= \frac{\pi}{16} . f . d^3$. Take f as 9000 lbs. per square inch.

   Therefore this may $= \frac{\pi}{16} . 9000 . 2^3$ inch-lbs.

   Key being 4 inches long in shaft, width ·625 inch:—Area $= 4 \times {\cdot}625$. Resistance to shearing $=$ area $\times f$. Take f as 10,000. This may $= 4 \times {\cdot}625 \times 10{,}000$ lbs.

   Moment of this about centre line of shaft $= 4 \times {\cdot}625 \times 1000 \times 1$ inch radius, inch-lbs.

   $$\therefore \frac{\text{strength of shaft}}{\text{strength of key}} = \frac{{\cdot}196 \times 9000 \times 8}{4 \times {\cdot}625 \times 10{,}000 \times 1} = \frac{1}{1{\cdot}75}.$$

   Key in shear is $1\frac{3}{4}$ times the strength of the shaft to resist pure torsion.

2. Describe, with sketches, the method of cutting a keyway, suitable for a hollow-back key, in a belt pulley.
3. Explain how the slot for a sunk key is machined in a shaft. Sketch the method of holding the shaft during the process, also the shape of the cutting tool employed.

BELT PULLEY.

Drawing No. 14.

To connect and drive one shaft from another, when the axes are parallel, and some distance apart, a flexible band, usually of leather, is used, running on wheels or pulleys mounted one on each shaft.

To produce motion of the driven shaft there must be a difference of pull, or tension, in the two sides of the belt. We have the tight side and the slack side. To enable this difference of tension to exist, there must be friction of the belt on the pulley.

Fig. 67.—Cast-iron Pulley.

Fig. 67.—The pulley consists of a light iron rim, connected to the hub or centre boss by arms, which may be straight or curved. Curved arms are preferable, as they tend to eliminate strains which may be set up by unequal cooling while the metal is solidifying in the sand, after casting.

Draw to a scale of quarter full size the solid cast-iron pulley given, adding an outside end elevation.

To enable the belt the better to retain its position on the pulley, the surface may be rounded instead of being made flat. Thus, if the pulley be slightly coned, the belt, owing to its lateral stiffness, tends to climb to the highest diameter (see fig. *a*). Making a double cone and rounding off the sharp edge leads to the curved rim. The amount of rounding on the face is usually about $\frac{1}{4}$ inch per foot of width, but depends on the speed.

If the axes of the shafts are not parallel, the belt will retain its position on the pulleys, in a belt drive, if the central plane of the receiving pulley passes through the point of delivery of the other pulley.

Examples—

1. A piece of leather belting 8 inches long, $1\frac{5}{8}$ inches wide, $\frac{3}{16}$ inch thick weighs 43·2 grams. Show that 1 cubic inch weighs $\frac{5}{8}$ oz., or ·039 lb.
2. The pulley, Drawing No. 14, is on the shaft of a motor taking 40 amperes at 220 volts, and running at 760 revolutions per minute. Show that the linear speed of the belt is 4773 feet per minute, and that the difference of tension in the two sides is 81·5 lbs.
3. Sketch and describe the construction of a wood pulley; and describe, with sketches, the different ways of making the joint in a leather belt.

LEATHER BELT. 3" WIDE $\frac{1}{4}$" THICK.

JOINT SPLICED, CEMENTED AND STITCHED.

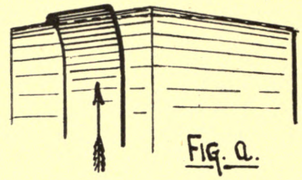
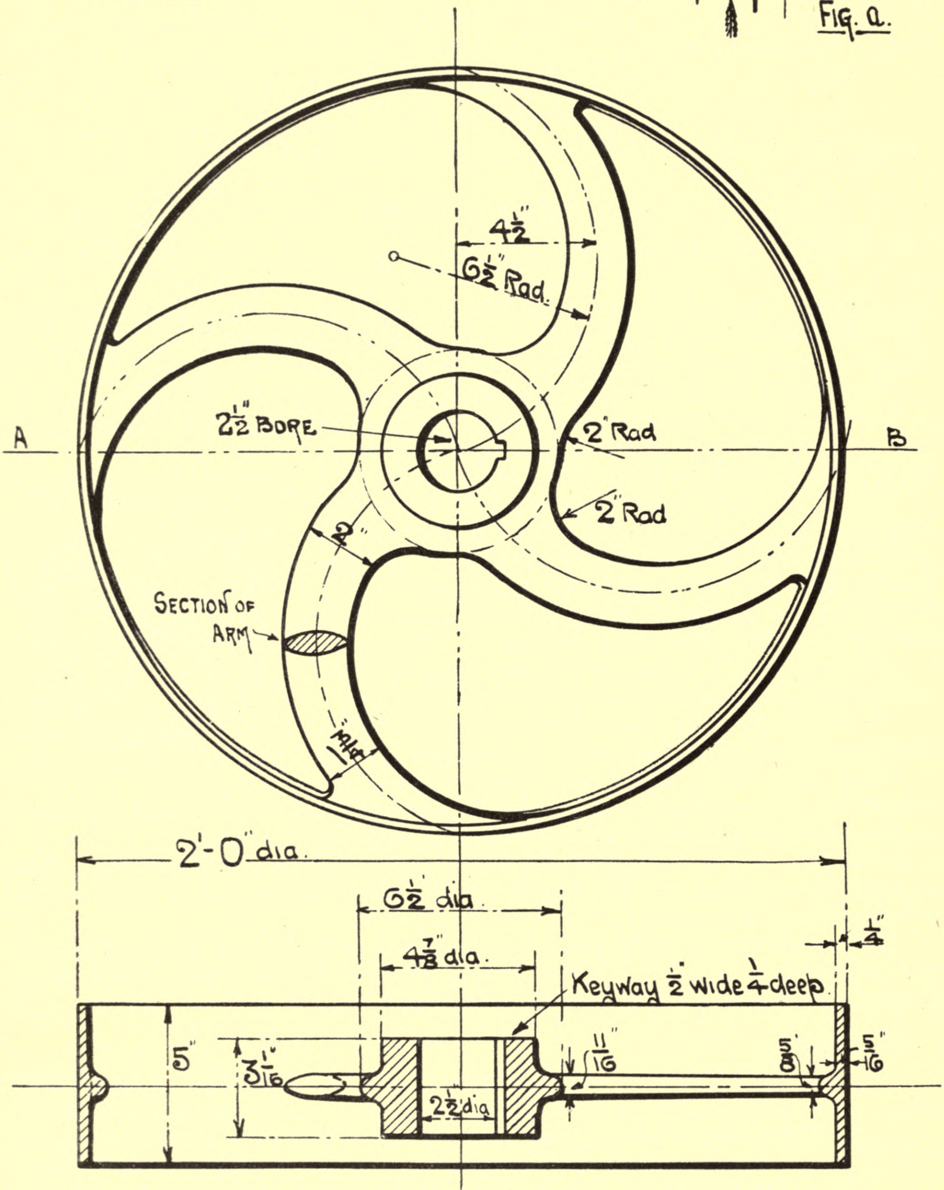


FIG. a.



SECTION ACROSS AB.

DRAWING No. 14.

SCALE. $\frac{1}{4}$. FULL SIZE.

CAST IRON. PULLEY. 24" DIA.

SPLIT BELT PULLEY.

Drawing No. 14A.

Fig. 68.—For main and line shafting it is convenient to be able easily to add, remove, or shift a pulley without disturbing the shafting. To meet this requirement split pulleys are used. They may be fixed to the shaft by key, set screws, or simply tightened up to grip. To enable a stock pulley to be rapidly used on any size shaft, it is stocked bored out big, and then fitted with a bush to suit the shaft.

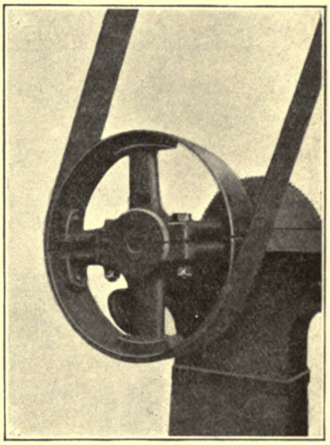


Fig. 68.—Split Pulley.

Draw to a scale of half full size the pulley given, showing a front elevation, outside side elevation, and a plan in section through the horizontal centre line.

The pulley is split, has a wrought-iron rim, cast-iron arms, and is bushed. It is used for driving a circular saw.

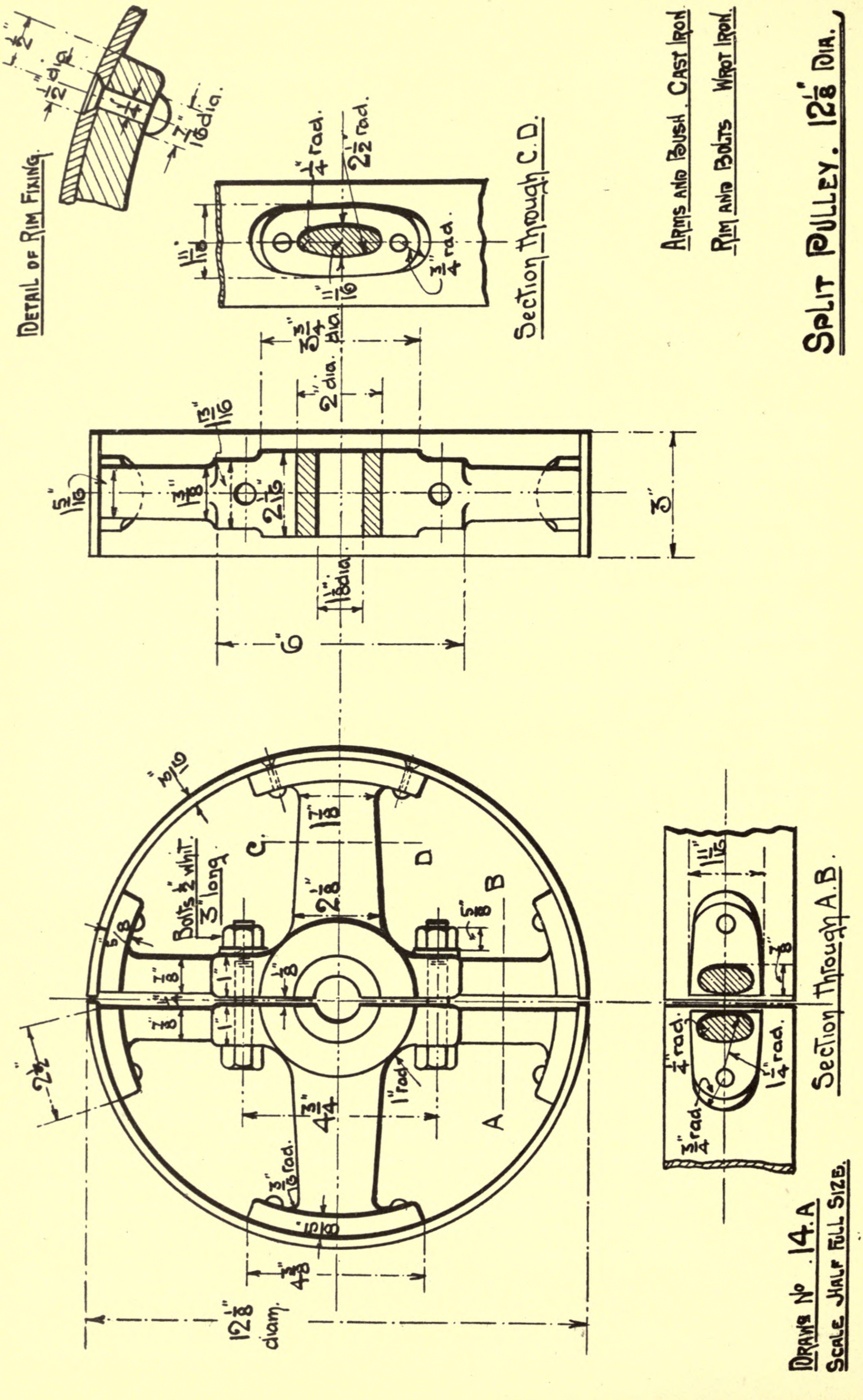
When made of cast-iron, pulleys up to 15 inches diameter are cast in halves and planed to fit together. Above this diameter they are usually split with cores during casting.

When used for driving at high speeds, as in dynamo and saw work, the pulleys must be accurately balanced.

When used in a drive where sudden resistances are met, which make the belt slip over the face of the pulleys, the driven pulley should be flanged to prevent the belt falling off.

Examples—

1. What are the advantages obtained by the use of wrought-iron pulleys as against cast-iron pulleys? Under what circumstances would a split pulley be used? What determines whether a pulley should be single-armed or double-armed?
2. Make a hand sketch, complete with dimensions, of a split belt pulley, with wrought-iron rim, mild-steel arms, and cast-iron boss. Diameter, 18 inches; face, 6 inches; suitable for 3 inches diameter shaft. Give a detail sketch showing the boss, and the method of fixing on the shaft.


Detail of Rim Fixing.
Section through C.D.
Arms and Bush Cast Iron.
Rim and Bolts Wrot Iron.
Split Pulley. 12 1/8" Dia.
Bolts 1/2" whit. 3" long
Section through A.B.
Drawg No 14.A
Scale Half Full Size.

3. The 24-inch pulley, Drawing No. 14, drives a 12-inch pulley. Distance between shaft centres, 12 feet. The belt is 3 inches wide, ¼ inch thick, with cemented joint. Show that the maximum tension in the belt is 140 lbs., and T_2 59 lbs., if the relation between the tensions in the two sides of a belt, when it is on the point of slipping, is given by $\frac{\tau_1}{\tau_2}=\epsilon^{\mu\theta}$ or $\log \tau_1 - \log \tau_2 = \mu\theta \log \epsilon$, and $\tau_1 - \tau_2$ is obtained from Example 2, page 107.

   Where τ_1 is the maximum tension.
   τ_2 the minimum.
   ϵ is constant and $= 2{\cdot}718$.
   μ is the coefficient of friction, leather on cast-iron; varies from ·2 to ·4; take as ·28.
   θ is the angle of contact of belt on smaller pulley measured in radians, and in this example $= 3{\cdot}1$.

4. To calculate the velocity of the driven shaft, it is more accurate to take the diameter of the pulley plus the belt thickness, instead of the pulley diameters.

   Example.—By using a speed-counter it is found that a pulley 18 inches in diameter makes 750 revolutions per minute. A belt ¼ inch thick running on it drives a pulley 8¾ inches diameter. When running light, that is, with no load on the driven pulley shaft, the speed-counter shows that it makes 1522 revolutions per minute. Compare this speed with that calculated, (1) taking belt thickness into account, and (2) neglecting belt thickness.

   It should be observed that motion of the driven pulley is lost (1) by the belt actually slipping on the face of the pulley, and (2) by creeping. The total slip depends altogether upon the conditions of the drive, *i.e.* belt speed, power transmitted, initial tension, etc. A usual allowance is 2 to 3 per cent.

5. *The power transmitted by a belt depends on* the tension, arc of contact, speed, and frictional grip of belt on pulley. A belt will slip on its pulley long before it will break. To improve the grip, belt dressings are used. As the belt runs on the pulley, air is taken in between them, and acts as a lubricant. To allow this to escape the pulley rim is perforated, or holes made along the centre line of the belt. As the speed increases the effect of centrifugal force is to throw the belt away from the surface of the pulley, thus diminishing the grip. The speed at which a given belt will transmit maximum power is given by

$$v=\sqrt{\frac{\tau \times 32{\cdot}2}{3 \times w}} \text{ feet per second.}$$

   τ is the maximum allowable stress in the belt, for leather breaking strength, which is $= 4200$ lbs. per square inch, or 1050 lbs. per inch width for ¼-inch belting. The strength of the laced joint is about one-third of this, or 350 lbs. Taking a working stress of one-fifth of this, we have 70 lbs. per inch of width. The weight of

1 foot of belting, 1 inch wide, $\frac{1}{4}$ inch thick, being 0·12 lb., the speed for maximum power is 4740 feet per minute. Verify this.

Taking into account the bending of the belt round the pulley, which at high speeds is very destructive to the belt, the average speed of leather belting does not exceed 2000 to 3000 feet per minute.

6. *Creeping of Belts.*—Nominally, with a driven pulley half the diameter of the driver, the driven shaft should make twice the number of revolutions per minute made by the driving shaft. Belts will not transmit an accurate velocity ratio, owing to creeping of the belt on the surface of the pulley. Thus a unit length of belt in an unstrained condition will, owing to elasticity, have a length $\left(1+\frac{\text{tension}}{\text{area}\times\text{modulus}}\right)$ when running, and will vary on the tight and slack sides.

The velocity of the belt entering the driving pulley is equal to that of the pulley, so that the belt, passing from the tight to the slack side, contracts, and does this even against the motion of the pulley.

The driven pulley has a velocity equal to that of the slack side of the belt, which in passing over the pulley expands against the motion of the pulley, and work is lost in both cases, causing heating of the belt.

Roughly, therefore,

$$\text{Revs. of driven shaft} = \text{Revs. of driving shaft} \times \frac{\text{dia. of driving pulley.}}{\text{dia. of driven pulley.}}$$

To take into account creeping due to the elasticity of the belt, this result would have to be multiplied by

$$\frac{1+\dfrac{\text{min. tension}}{\text{area}\times\text{modulus}}}{1+\dfrac{\text{max. tension}}{\text{area}\times\text{modulus}}}.$$

Example.—Show that the effect of this in the foregoing example is only $\frac{1}{2}$ per cent., taking the modulus of elasticity for leather belting as 25,000 lbs. per square inch.

ROPE PULLEY.

Drawing No. 15.

As the amount of energy to be transmitted increases, the use of single leather belting becomes more and more objectionable, owing to the great weight, dimensions, cost, and liability to failure of the belt required. To meet the difficulty two thicknesses of single belting are stitched together, forming a double belt, or another belt is run on top of the one already running on the pulleys. Woven belting may be used, and has the advantages of reduced weight and greater flexibility; but where the rate at which energy has to be transmitted between centres some distance apart is considerable, rope-driving is used. This form of driving is also convenient where the driven pulley is awkwardly placed relative to the driver, the rope being led to and from it by simple guide pulleys.

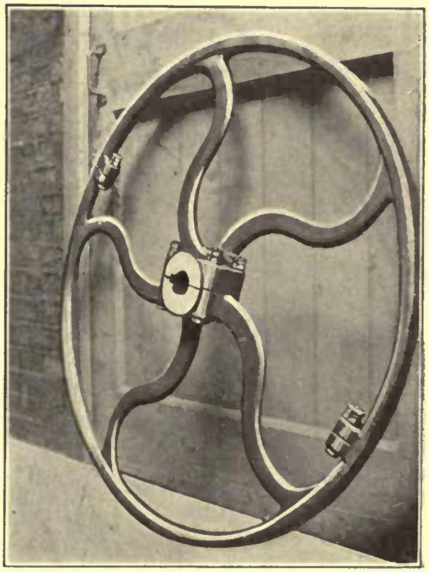


FIG. 69.—Single Rope Pulley.

With a number of ropes on a pulley, each rope is usually complete in itself, the joint being made by a splice not less than 50 rope diameters long, and each rope is looked upon as transmitting its proportional part of the total power.

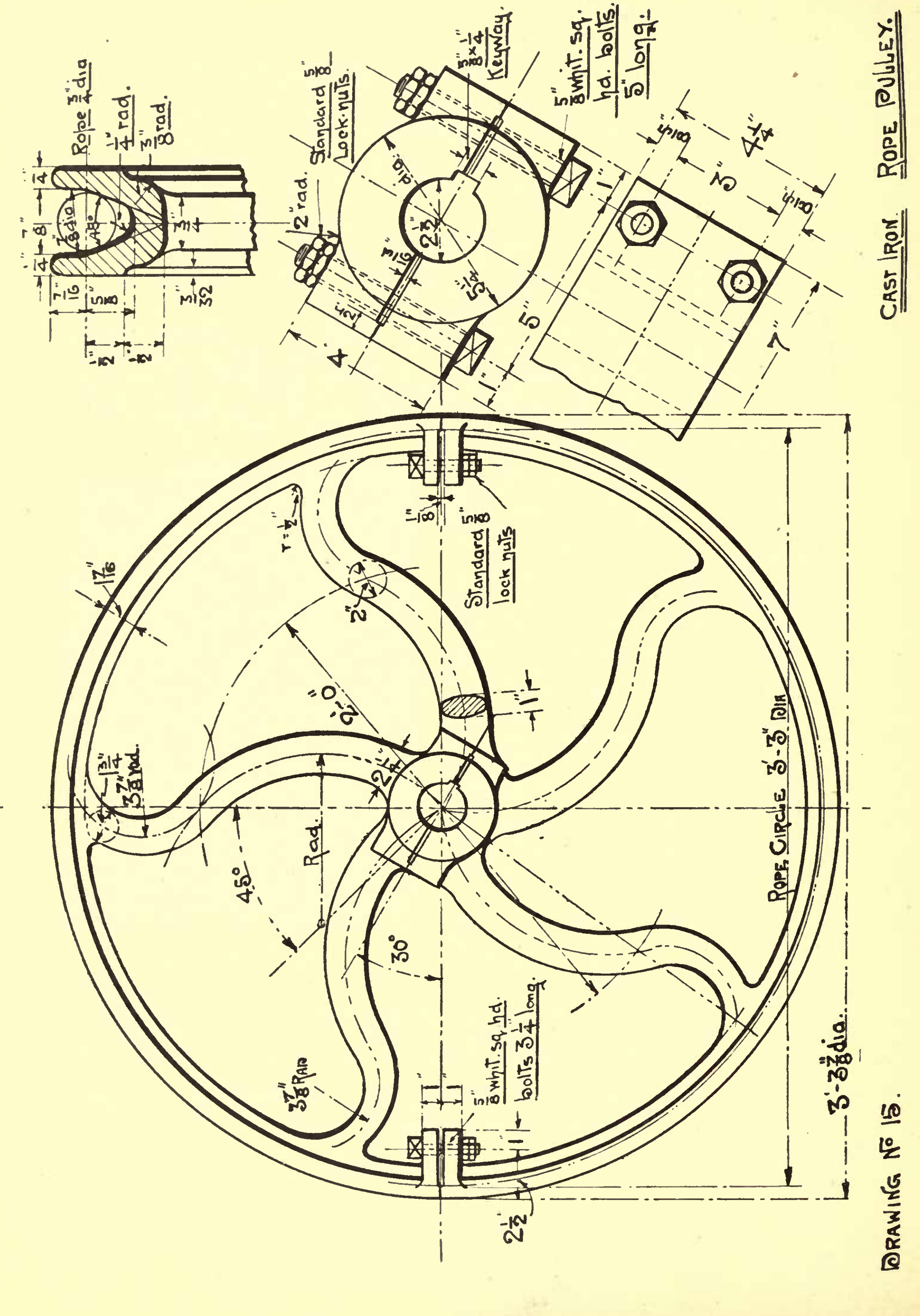
The rope drives by wedging in the groove, and to increase the arc of contact the lower side of the drive should be the tight side.

Fig. 69.—The pulley shown is split in the directions indicated by means of cores, and is held together by bolts passing through cored holes.

Draw to a scale of quarter full size, an outside front elevation, and a side elevation as a section through the vertical centre line.

To a scale of full size, details of the rim section, the boss, and the rim joints.

Example.—The pulley is on a shaft making 300 revs. per minute. What is the linear speed of the rope in feet per minute?


ROPE PULLEY.
CAST IRON.
DRAWING No 15.
ROPE CIRCLE 3'-3" DIA
Standard $\frac{5}{8}$" lock nuts
$\frac{5}{8}$" whit. sq. hd. bolts $3\frac{1}{4}$" long.
Standard $\frac{5}{8}$" Lock nuts.
$\frac{5}{8}$" whit. sq. hd. bolts. 5" long.
Keyway.
Rope $\frac{3}{4}$" dia
$\frac{1}{4}$" rad.
$\frac{3}{8}$" rad.
2" rad.

MULTIPLE ROPE PULLEY.

Drawing No. 15A.

THE size of a driving rope is given either by its diameter or its circumference. The size of rope used varies from $\frac{1}{2}$ inch to 2 inches diameter. The form of the groove is most important; such a groove for a $\frac{3}{4}$ inch diameter rope is given. The pulley shown is made in halves, with planed joint, and is gripped and keyed on the shaft. Instead of arms, the rim is connected to the boss by a plate, which is lightened by having circular holes with rounded edges cast in.

Draw to a scale of full size—

A section of the rim, indicating the joint flanges by dotted lines.
An end view of the joint.
A plan looking at the inside of the rim joint, showing the bolts in position.

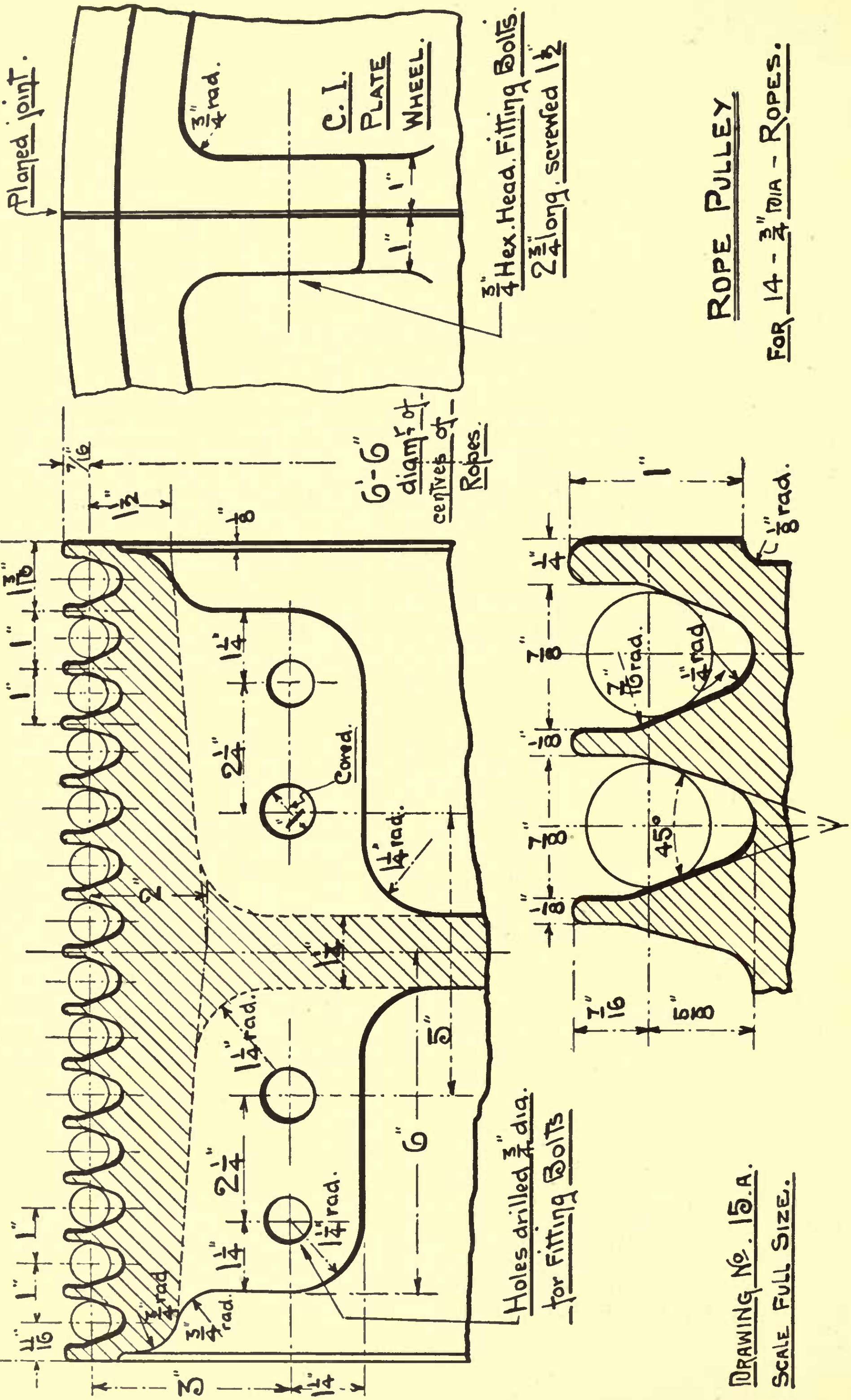
Examples—

1. What is the linear speed of the rope in feet per minute, the pulley making 170 revolutions per minute? (3470.)
2. Five ropes on the left-hand side together drive a dynamo giving 200 amperes at 100 volts. The efficiency of the dynamo being 90 per cent., what is the effective working tension in each rope $(\tau_1-\tau_2)$? (56·6 lbs.)
3. The shaft of this dynamo is 11 feet centres with the main shaft, and it makes 650 revs. per minute. What is the diameter of the rope circle of its pulley? (21 inches.)
4. When the rope is just on the point of slipping, which is determined by the initial tension, which equals $\frac{\tau_1+\tau_2}{2}$, the relation between the tension in the tight side, τ_1, and the tension in the slack side, τ_2, of the drive is given by

$$\frac{\tau_1}{\tau_2}=\epsilon^{\frac{\mu\theta}{\sin\frac{\phi}{2}}},$$

where μ is the coefficient of friction, say ·28, θ is the angle of contact of the rope on the smaller pulley, in this example $=2·7$ radians; ϕ is the angle of the groove, usually 45°.

From this, show that the maximum stress in each of the $\frac{3}{4}$-inch ropes is 66·25 lbs., or in lbs. per square inch is 150.



ROPE PULLEY
FOR 14 - 3/4" DIA - ROPES.

DRAWING No. 15.A.
SCALE FULL SIZE.

5. The centrifugal effect as the rope passes over the pulley is to reduce the driving grip. The tension produced in the rope due to centrifugal force is

$$\tau = \frac{wv^2}{g} \text{ lbs. per square inch.}$$

w = weight per foot of rope, say 1 square inch area = ·27 lb.; hence show that in the example $\tau = 28$ lbs. per square inch.

6. The total maximum stress in the rope is that due to driving plus that due to centrifugal effect. The breaking strength of a cotton rope being 7000 lbs. per square inch of area, show that the working stress is $\frac{1}{39}$ of the breaking stress.

7. The speed at which a rope will transmit maximum power is shown by making a table for velocities from 3000 to 6000 feet per minute.

Velocity of belt. Feet per second. (1)	$\tau = \frac{wv^2}{g}$ (2)	Max. working stress − τ. (3)	Rate at which energy is transmitted is proportional to (1) × (3).	Mark the velocity for which energy is a maximum.

Take a maximum stress in the material of the rope of 175 lbs. per square inch. The result is more easily obtained from the formula

$$v = \sqrt{\frac{\tau \times g}{3w}} \text{ feet per second.}$$

Taking τ as 175 lbs. per square inch, and w ·27 lb., we have $v = 5000$ feet per minute.

This does not take into account the depreciation of the ropes due to bending round the pulley, allowing for which the usual rope speed is about 4000 feet per minute.

COUNTERSHAFT FOR HALF-INCH SENSITIVE DRILL.

Drawing No. 16.

INDIVIDUAL machines are driven from the main shaft, through a countershaft which usually carries a fast and a loose pulley, and strap fork arrangement, making the stopping and starting of the machine independent of the main shaft and other machines. In many cases the countershaft carries a cone or multiple-pulley arrangement, enabling different speeds to be obtained for the machine spindle.

Fig. 72 is a line arrangement showing the way in which the above drilling machine is driven. The line shaft makes 300 revolutions per minute, carries a pulley 12 inches diameter, $2\frac{1}{4}$ inches face, which by means of a $1\frac{3}{4}$ inches wide single leather belt drives a pulley $7\frac{7}{8}$ inches diameter, $2\frac{1}{4}$ inches face, on the main countershaft. An 8 inches diameter, $4\frac{1}{2}$ inches face pulley on this countershaft, by means of a $1\frac{1}{2}$ inches wide single leather belt, drives either the fast or loose pulley on the machine or foot countershaft, which carries the strap-shifting arrangement. The foot countershaft carries a cone-pulley, which drives a second three-speed cone-pulley carried or running loose on a stud spindle. On this cone-pulley boss is keyed a 6 inches diameter plain pulley, from which a $1\frac{1}{2}$ inches wide link leather belt, running over guide pulleys, drives the drill spindle pulley, which is $3\frac{3}{4}$ inches diameter. To follow out the conditions of belt-driving for shafts the axes of which are not parallel, consider A as driver for C, C as driver for B, B for D, and D as driver for A.

Foot Countershaft.—Drawings numbered 16, 16A, 16B, and 16C show the general arrangement and details, while the general idea is given by fig. 70 and fig. 71.

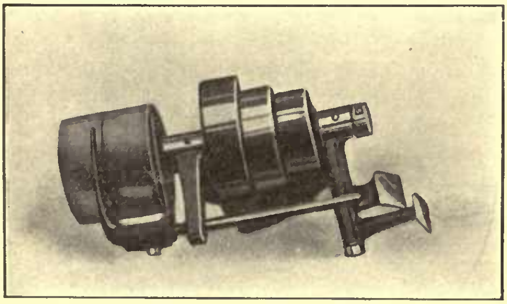


FIG. 70.—Foot Countershaft.

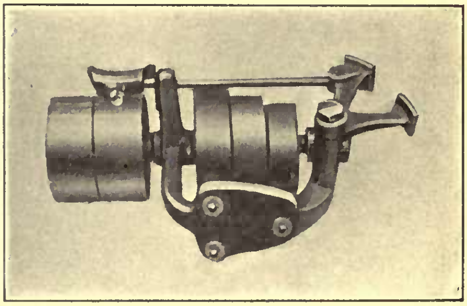
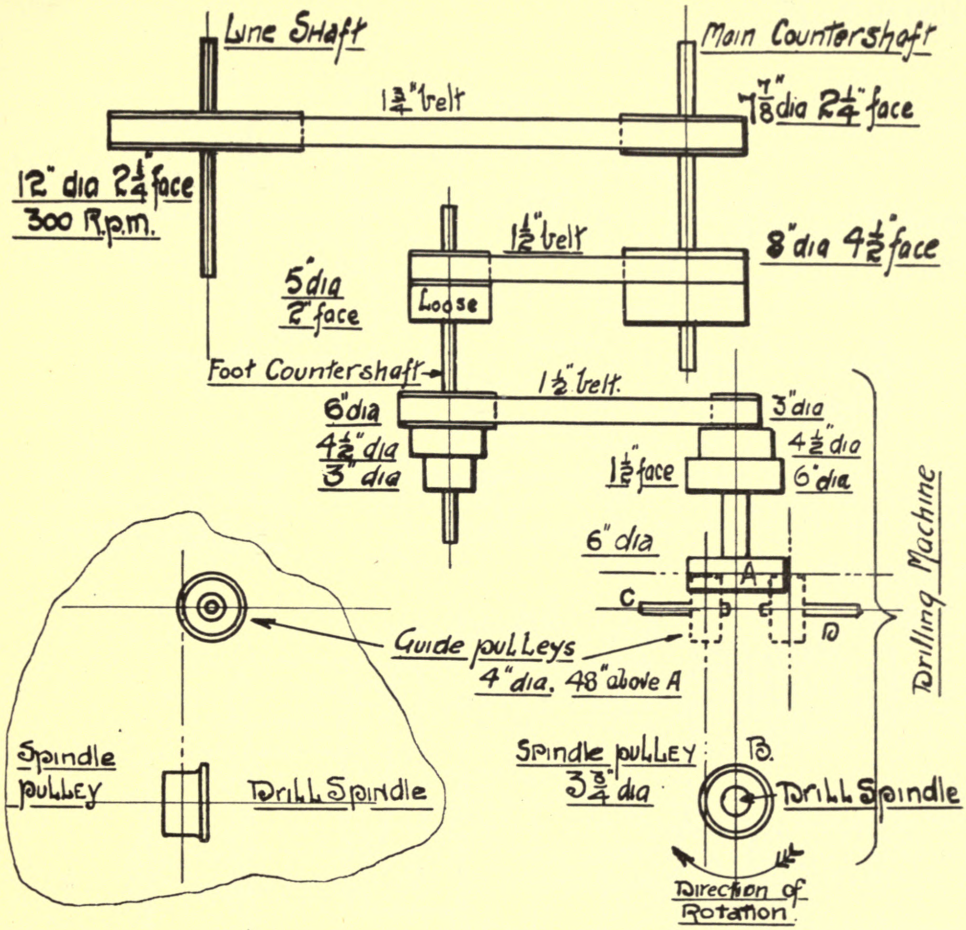


FIG. 71.—Foot Countershaft.

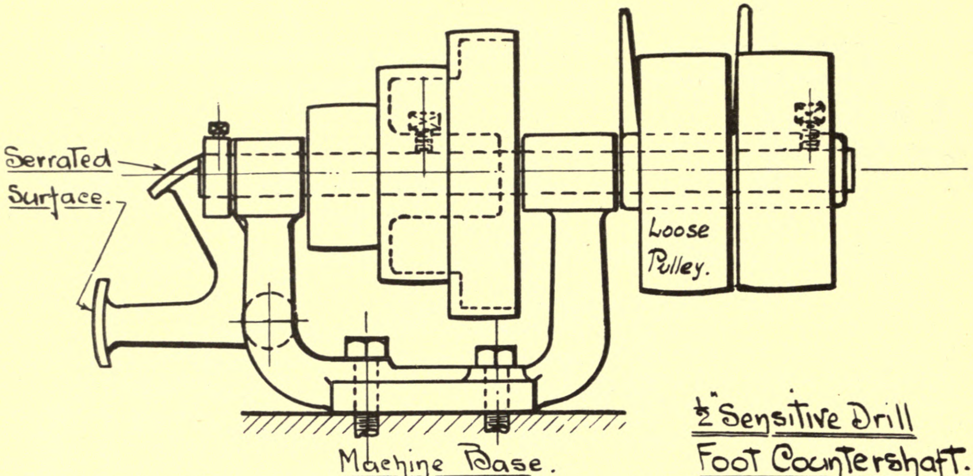


NOTE: A DRIVES B BY MEANS OF A 1½" LINK BELT. THE GUIDE PULLEYS CHANGE THE DIRECTION OF MOTION OF THE BELT AND IN ALL CASES THE PLANE OF THE DRIVING PULLEY IS TANGENT TO THE FACE OF THE DRIVEN PULLEY AT THE POINT WHERE BELT ENTERS THE DRIVEN PULLEY.

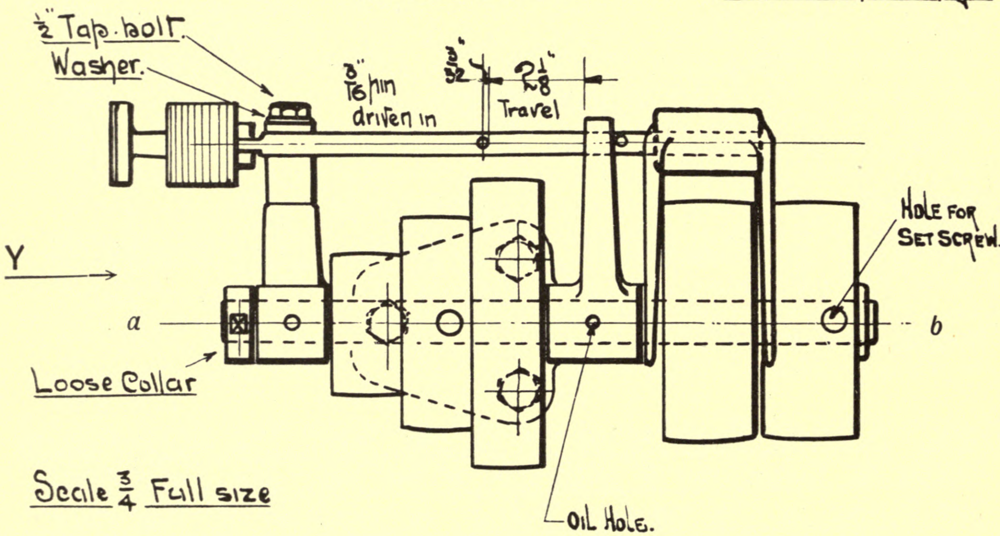
DRILL SPEED IN REVS. PER MIN.	CALCULATED	MEASURED	% DIFFce
MAXIMUM.	2340	1775	-24·1
MIDDLE.	1170	1003	-14·3
MINIMUM.	585	530	-9·4

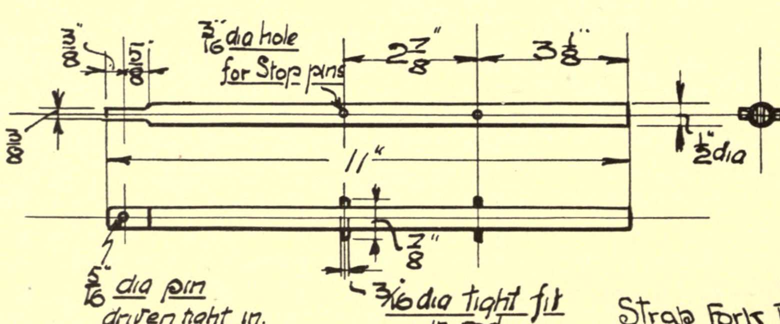
FIG. 72.—Diagrammatic Sketch showing Driving and Drill Spindle.

Drawing No 16



1/2" Sensitive Drill Foot Countershaft.





Strap Fork Rod.
One off Mild Steel.

Card No 3. Draw. No 16.c.

Draw, in all cases to a scale of three-quarters full size—

1. Separate cards giving each detail complete, with all necessary views and dimensions, numbering the drawings 16A, 16B, 16C.
2. A general arrangement, Drawing No. 16, showing—
   - (*a*) An elevation with the bracket and pulleys in section, along a plane represented by the centre line *ab* in plan.
   - (*b*) A plan as shown.
   - (*c*) An end elevation in correct projection looking in the direction of the arrow Y.

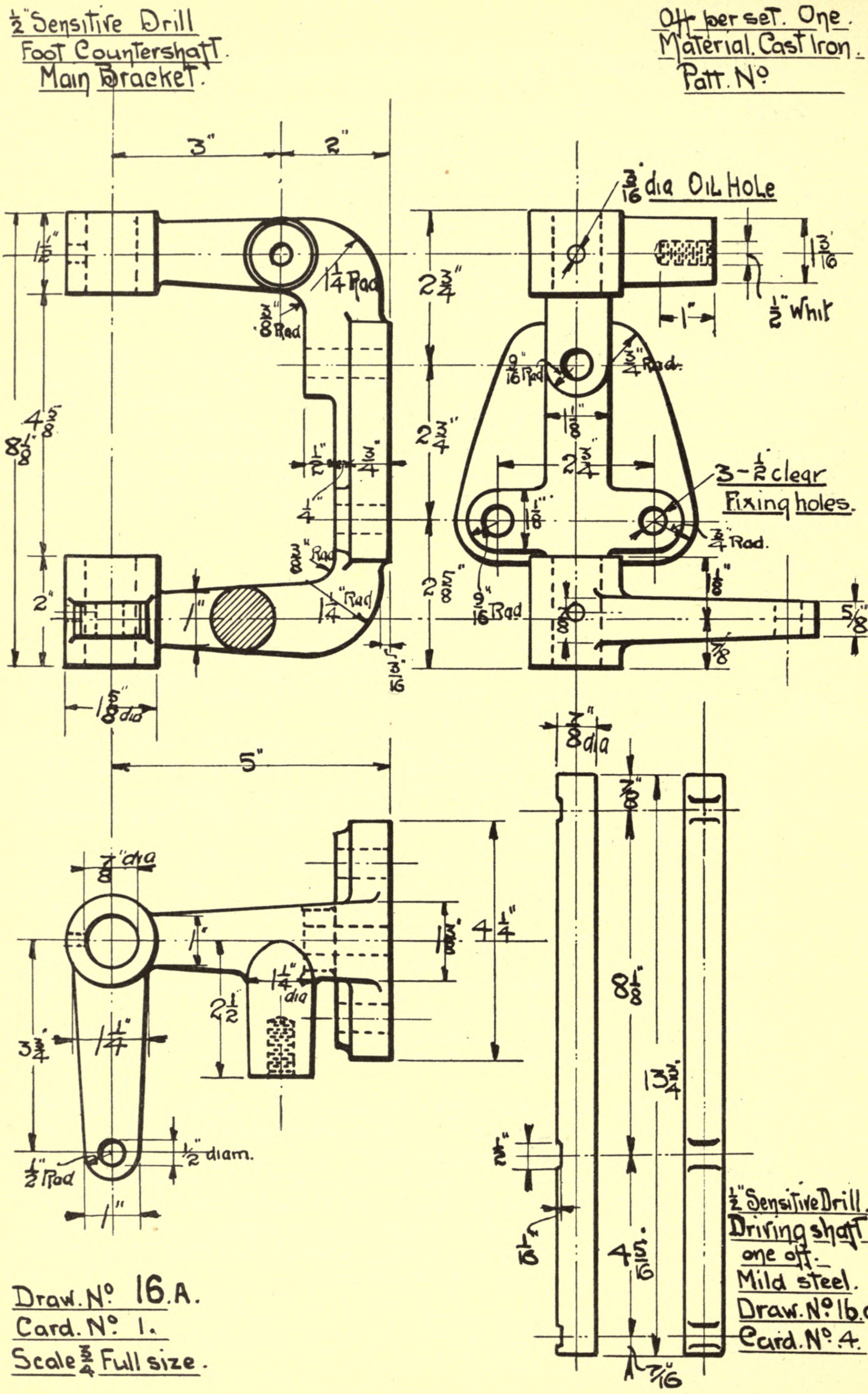
The countershaft is on the floor level. For stopping and starting the machine, *i.e.* the drill spindle, the serrated foot-lever is rocked over by means of the foot, leaving the hands free for feeding the drill and operating the job.

To be satisfactory, a strap fork arrangement must not allow the strap to creep along from the loose to the fast pulley when the machine is at rest; that is, the strap fork gear must have definite stable positions for the belt on either of the pulleys. The strap fork operates on that side of the belt which is approaching the driven pulley.

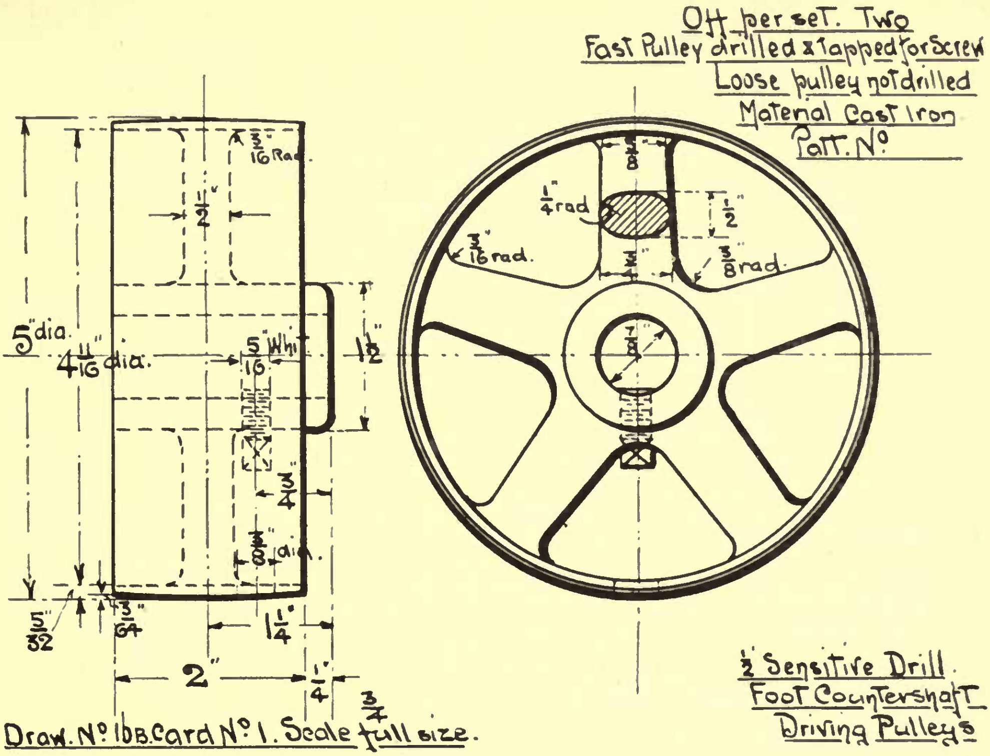
Examples—

1. Make a table showing the linear speed in feet per minute of each belt shown in the arrangement fig. 72.
2. From the size of pulleys given, calculate the revolutions per minute which each shaft and the drill spindle ought to make, neglecting loss of motion due to creeping and slip of the belts, the main shaft making 300 revolutions per minute.
3. The actual speeds measured being: main shaft, 300; main countershaft, 445; foot countershaft, 684; drill spindle, minimum 530, middle 1003, maximum 1775 revolutions per minute,—verify the percentage difference between the calculated and obtained speeds of the drill spindle.

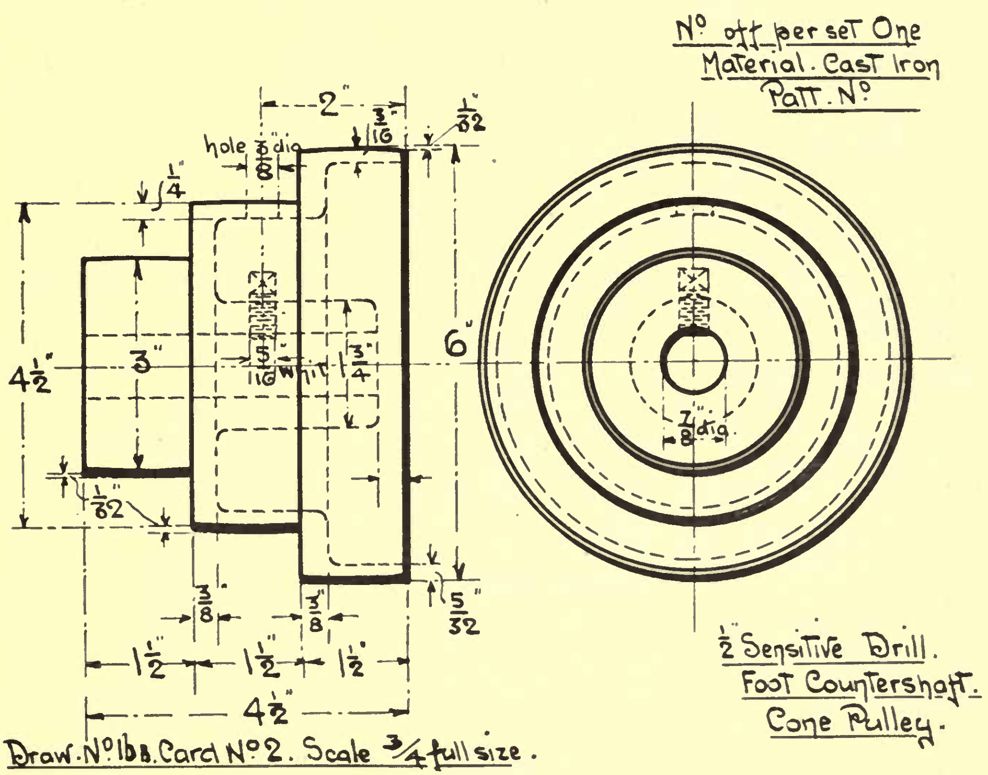
   The above measured speeds are with the drill running free. Thus, when drilling a $\frac{3}{8}$ inch diameter hole in soft cast-iron, the speed of the drill spindle on the minimum speed is 474 revolutions per minute, as against 530 when running free.
4. The machine drills a $\frac{3}{8}$ inch diameter hole through soft cast-iron, and makes 474 revolutions per minute. What is the periphery velocity of the drill in feet per minute?
5. The drill goes through $\frac{7}{8}$ inch, drilling the above hole, in 31 seconds. How many revolutions does the drill make per 1 inch of drill feed?
6. What is the usual periphery drill velocity when drilling mild steel, cast-iron, and gun-metal? How many revolutions of drill per inch of feed is usually reckoned on?
7. Sketch, and describe how a speed-counter is used to obtain the speed of a shaft when the end is free and accessible, also how the speed of a pulley is obtained in revolutions per minute when the pulley runs loose on a stud or spindle. This method also applies to a shaft the ends of which are inaccessible.



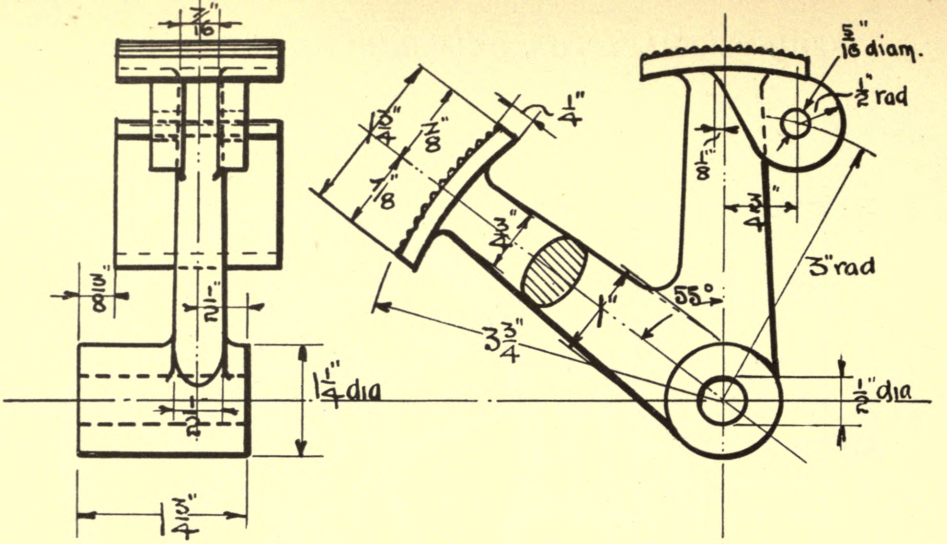
½" Sensitive Drill
Foot Countershaft.
Main Bracket.
Off per set. One.
Material. Cast Iron.
Patt. No.
3/16" dia Oil Hole
½" Whit
3 – ½" clear
Fixing holes.
Draw. No. 16.A.
Card. No. 1.
Scale ¾ Full size.
½" Sensitive Drill.
Driving shaft.
one off.
Mild steel.
Draw. No. 16.c
Card. No. 4.

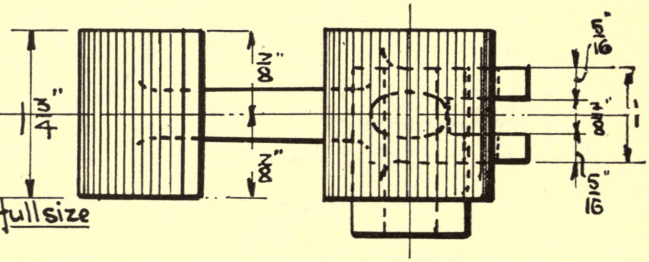


Off per set. Two
Fast Pulley drilled & tapped for Screw
Loose pulley not drilled
Material Cast Iron
Patt. No
5" dia.
4 11/16" dia.
5/16" Whit
1/2" Sensitive Drill.
Foot Countershaft
Driving Pulleys
Draw. No 1bB. Card No 1. Scale full size.



No off per set One
Material. Cast Iron
Patt. No
hole 3/8" dia
5/16" Whit
7/8" dia.
1/2" Sensitive Drill.
Foot Countershaft.
Cone Pulley.
Draw. No 1bB. Card No 2. Scale 3/4 full size.





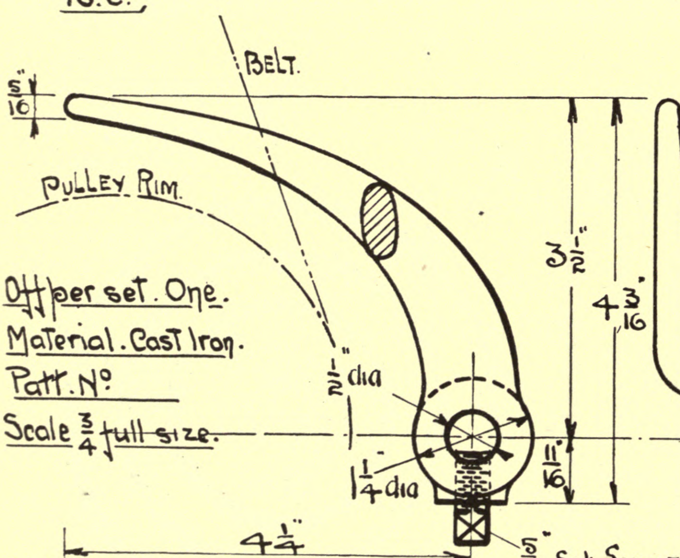
One off C.I. Patt. No

½" Sensitive Drill.

Foot Lever.

Draw. No Card No 1. Scale ¾ full size

16.c.

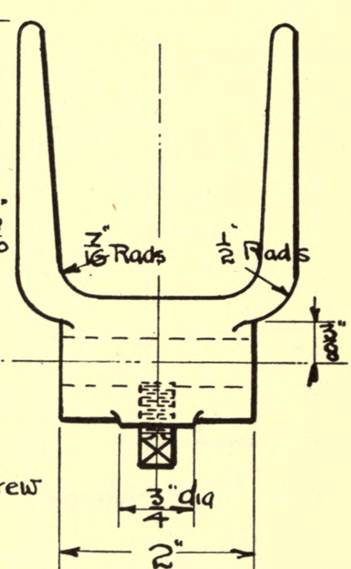


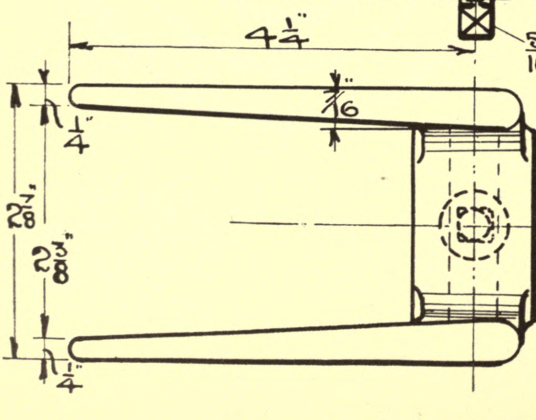
Off per set. One.

Material. Cast Iron.

Patt. No

Scale ¾ full size.





½" Sensitive Drill.

Foot Countershaft.

Strap Fork.

DRAW. No 16.c. CARD No. 2.

SOLID BEARING.

Drawing No. 17.

THE simplest form of bearing for a rotating shaft consists of a hole bored through a boss in the machine framing. This is useful and rigid, when the shaft and its details can be assembled, but it does not allow of adjustment during erection, or renewal after wear. The bearing given is bolted to the framing and is bushed with gun-metal. The bush is forced into the casting, and prevented from rotating by the two grub-screws.

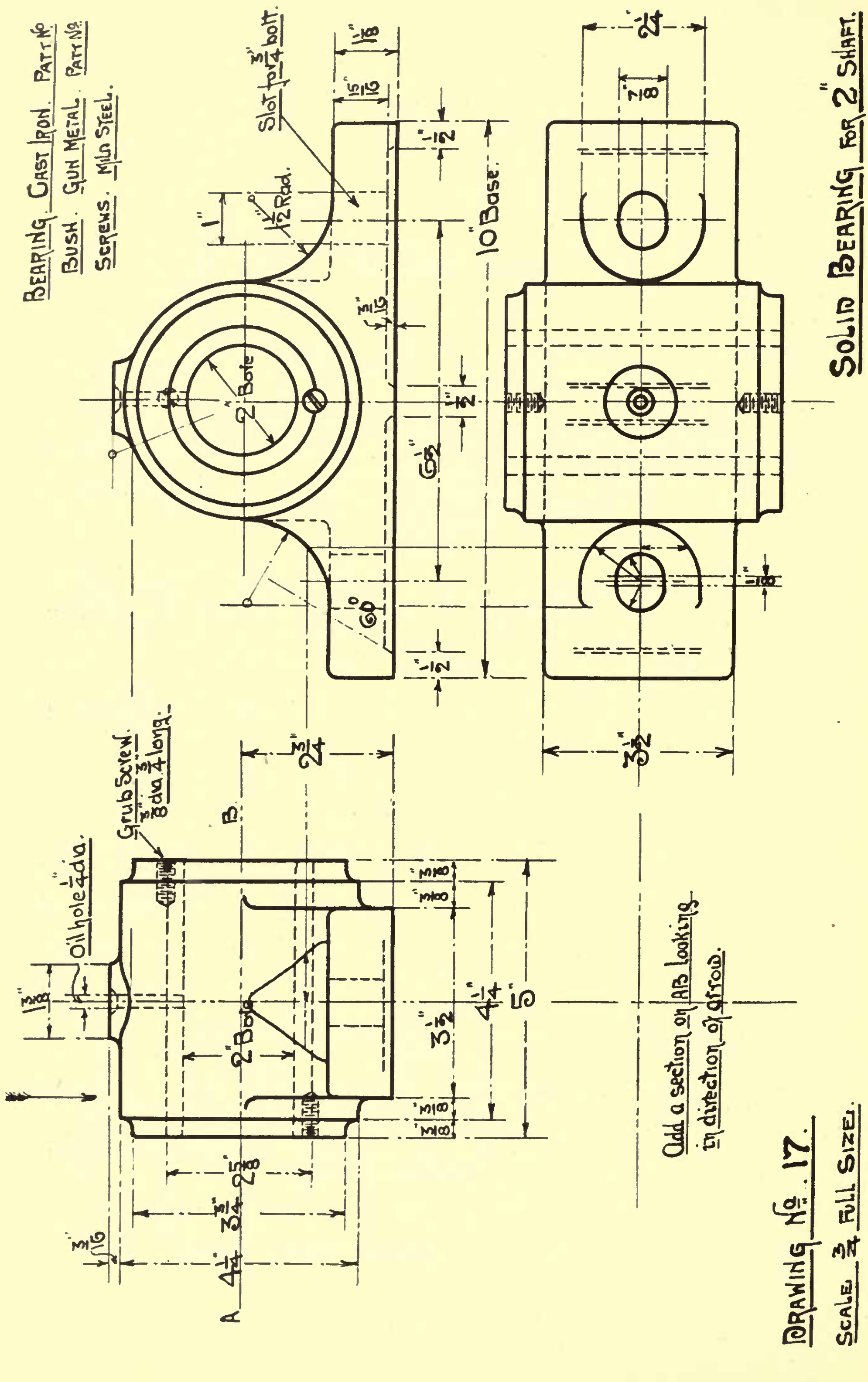
Draw to a scale of three-quarters full size, the views given, adding the fixing bolts, and drawing the sectional plan in correct projection.

Examples—

1. The bush is usually spoken of as "the brass bush": carefully note that it is made of gun-metal. What is the difference between gun-metal as used for a bearing, and brass as used for details which have to be non-corrosive, non-magnetic, or are to have a good appearance ?
2. What value of metal is there in each lb. of alloy, given the following compositions and prices ?

Alloy.	Composition by Parts.				Prices of Metal per Ton.			
	Copper.	Tin.	Zinc.	Antimony.	Copper.	Tin.	Zinc.	Antimony.
Gun-metal .	88	10	2	...	£	£	£	£
Brass . . .	62	1	37	...	56	125	18	33
White metal.	3·7	89·1	...	7·4				

Lubrication.—The most important point in connection with a bearing is its lubrication. When one body moves relative to another resistance is experienced, work is done, and mechanical energy is converted into heat energy. The resistance is known as friction, and a large percentage of the power which should be transmitted can easily be dissipated by frictional losses in the bearings. The effort required to move one body relative to another depends upon the conditions existing between the two contact surfaces. Thus we may have two metal surfaces in more or less good contact, or the two surfaces may be separated by a film of air, or a film of oil. To get one detail in motion relative to the other, there is a resistance called the **friction of rest** to be over-


Bearing. Cast Iron. Patt No.
Bush. Gun Metal. Patt No.
Screws. Mild Steel.
Slot for 3/4" bolt.
1 1/2" Rad.
2" Bore
10" Base.
Oil hole 1/4" dia.
Grub Screw. 3/8" dia. 3/4" long.
Add a section on AB looking in direction of arrow.
Solid Bearing for 2" Shaft.
Drawing No. 17.
Scale 3/4 Full Size.

come; when in motion, the resistance to be overcome to keep them in relative motion is called the **friction of motion,** and is less than that of rest.

The lubrication of a shaft in its bearing is by means of a film of oil between the shaft carrying the load and the bearing supporting it. The shaft being at rest, the film of oil is squeezed out, and we have metal on metal. On starting up, metal rubs on metal, and abrasion takes place. With a supply of oil ready, a film between the surface is rapidly formed by the surface of the shaft pulling in the oil. One side of this film adheres to the shaft, and the other to the bearing, and as the shaft turns this film is continuously sheared. Energy to do this is taken from that transmitted and reappears as heat, thinning the lubricant and reducing the thickness of the oil film. For perfect lubrication the oil film must be continuous, for immediately it gets broken there is, if it cannot re-form, metal rubbing dry on metal, the softer bearing grinding away, heat generated faster than it can be radiated or conducted, temperature rising, and finally the shaft sticking to the bearing. This is called seizing, and is due to the metal of the bearing alloying with the metal of the shaft.

SPLIT CAST-IRON BEARING.

Drawing No. 17A.

WITH perfect lubrication there is always a film of oil between the shaft and bearing, and the friction is then entirely due to the viscosity of the lubricant, and independent of the nature of the surfaces. If, however, metal rubs on metal, the friction depends upon the load, and the character of the surfaces. For efficient lubrication the pressure per square inch of projected area should not exceed 300 lbs. for a mild-steel shaft in a cast-iron bearing. To prevent excessive wear due to rubbing, the length of the bearing is usually three times the shaft diameter for rigid bearings, and four times for swivel bearings.

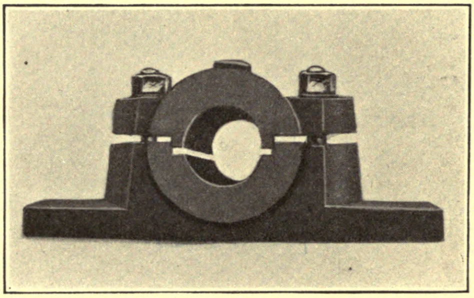


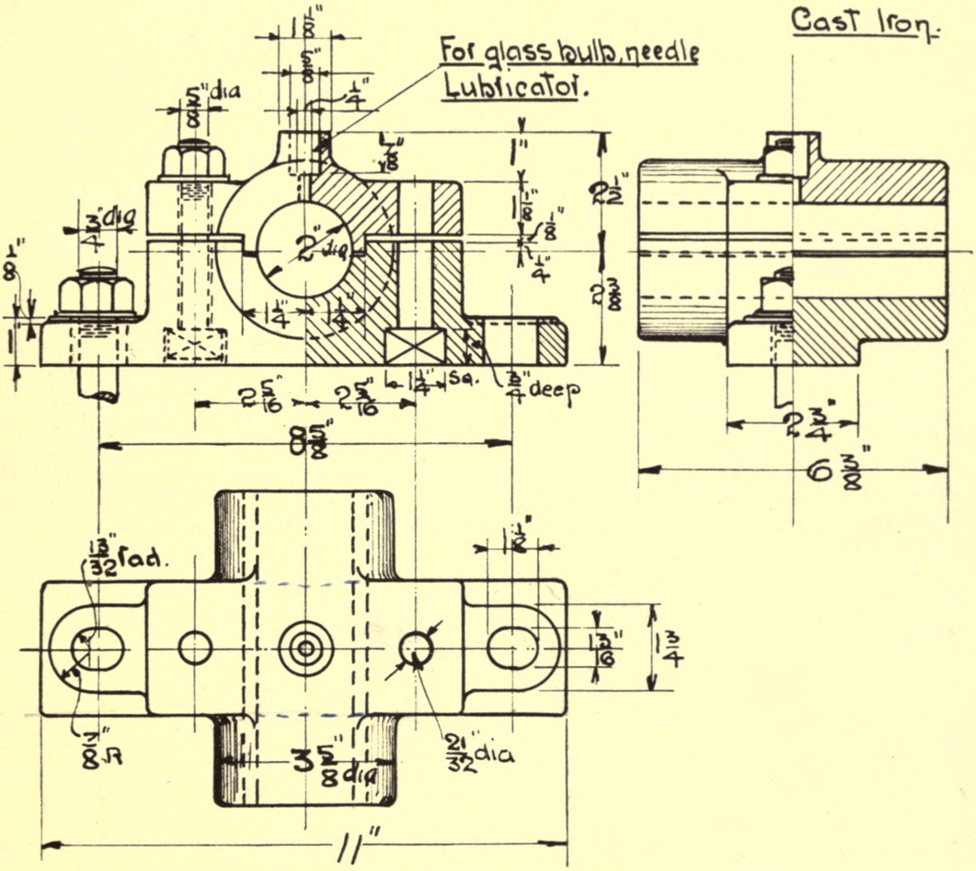
FIG. 73.—Split Bearing.

Draw to a scale of full size the three views as given, stating exactly what each view represents. Indicate by red lines the parts which would be machined.

Note.—Projected area = length × diameter of bearing.

Examples—

1. Explain how the relative values of oils for lubricating purposes are usually decided.
2. Describe how the comparative viscosities of lubricating oils may be determined.



Drawing No. 17-A
Scale Full size

SPLIT BEARING, FOR
2" DIA. SHAFT.

PEDESTAL OR PLUMMER BLOCK.

Drawing No. 17B.

GIVEN an isometric representation of the separate parts making up the pedestal.

Draw to a scale of full size, in rectangular projection, a side elevation, half in outside view, half in section along the centre line; an end elevation; and a plan showing the details assembled and fully dimensioned.

Example.—Explain the process of machining, boring, and fitting the brasses, *i.e.* the gun-metal steps, into the pedestal casting.

With a bearing made of softer material than the shaft, when the metals rub together dry, instead of one grinding the other away by abrasion, the tendency is for the softer to be burnished down. Hence the maximum working pressure of a mild-steel shaft working on gun-metal may reach 400 lbs. per square inch of projected area. As the tendency to wear is less and the renewal easier, the length of bearing for a pedestal is from 1·5 to 2 times the diameter.

Friction.—The effort required to keep one body moving relative to another is a fractional part of the reaction between the contact surfaces, denoted by μ, and called the coefficient of friction. The value of μ to suit any given conditions is determined experimentally, thus:—

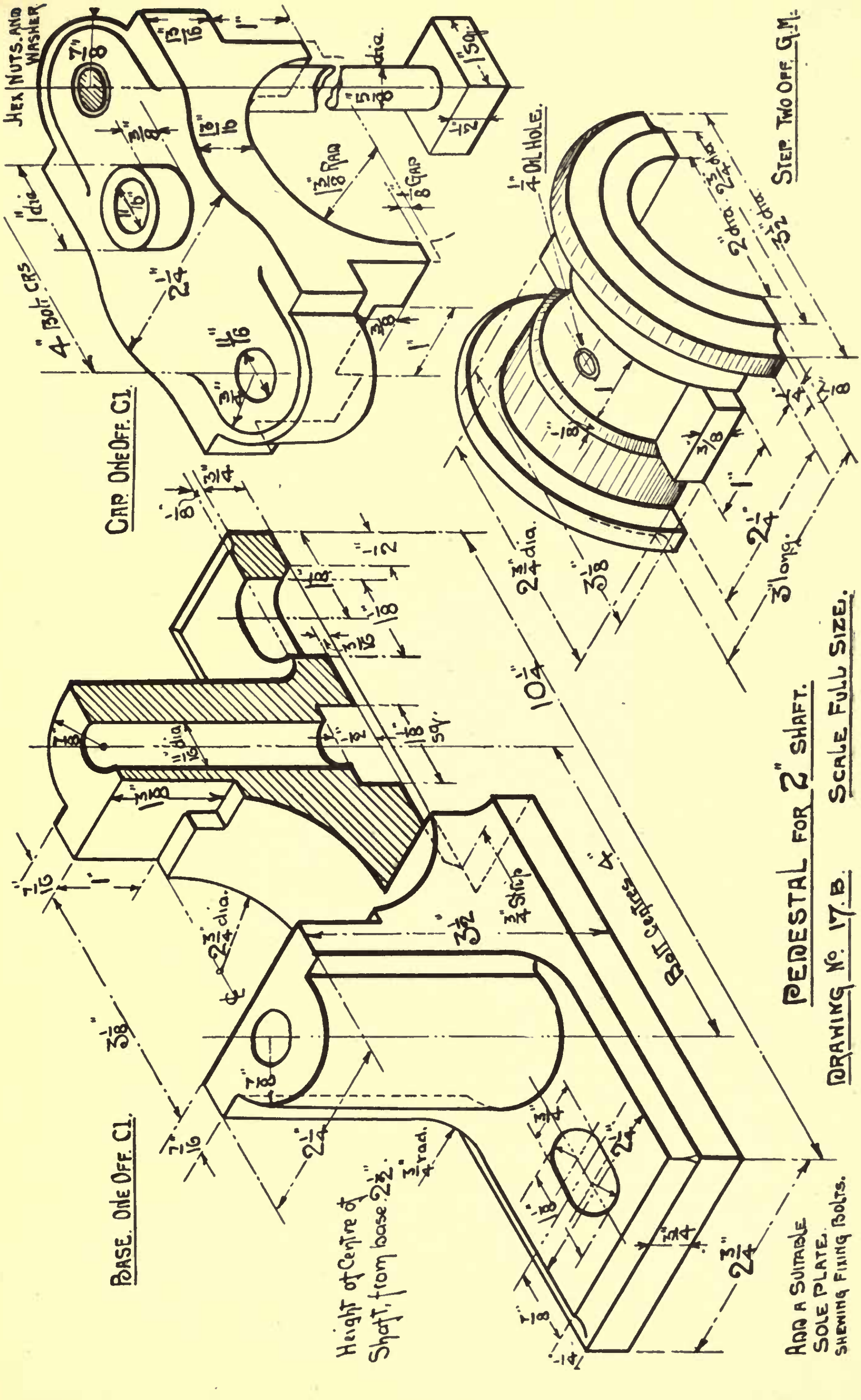
For metal sliding on metal, surfaces dry .	$\mu = \cdot 15$.
" surfaces well lubricated . . .	$\mu = \cdot 07$ to $\cdot 08$.
For journal bearings, surfaces dry . . .	$\mu = \cdot 18$.
" surfaces intermittently lubricated	$\mu = \cdot 07$ to $\cdot 08$.
" surfaces continuously lubricated .	$\mu = \cdot 03$ to $\cdot 05$.

A value of μ better representing modern conditions is that obtained from Mr Tower's experiments:—

For surfaces lubricated with an oil-bath .	$\mu = \cdot 27\sqrt{v \div p}$.
" " with syphon lubrication	$\mu = 2\cdot 6 \div p$.
" " with an oil-pad .	$\mu = \cdot 015$.

v = velocity of sliding surface in feet per second.
p = total load in lbs. ÷ length × diameter of bearing in inches.

For ordinary work the friction is assumed independent of the velocity and proportional to the load, μ being taken as equal to 0·05.


CAP. ONE OFF. C.I.
HEX. NUTS AND WASHER
4" BOLT CRS
1/4" OIL HOLE.
STEP. TWO OFF. G.M.
BASE. ONE OFF. C.I.
Bolt Centres
Height of Centre of Shaft, from base 2 3/4".
PEDESTAL FOR 2" SHAFT.
DRAWING No. 17.B.
SCALE FULL SIZE.
ADD A SUITABLE SOLE PLATE. SHEWING FIXING BOLTS.

MOTOR END BEARING.

Drawings No. 17c *and* 17c 1.

Is a type largely used, one at either end of the stator case to carry the rotor. The hard brass brush is held in position by the grub-screw; the shaft is lubricated by the hard brass ring, hung on, and driven round by the shaft, running in the oil-well, and carrying oil up to the top side of the shaft. To indicate the oil level in the well, a nipple with coned end is screwed into the boss; a copper pipe carrying the glass which shows the oil level has one end

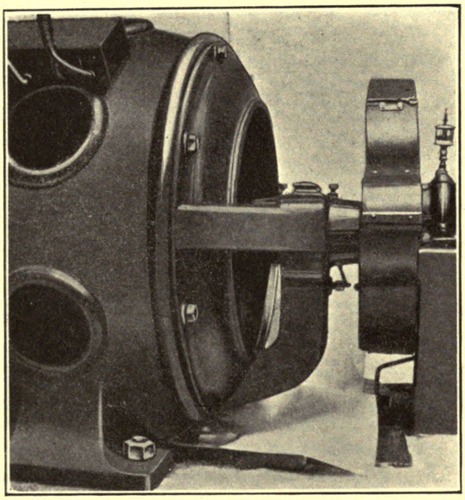


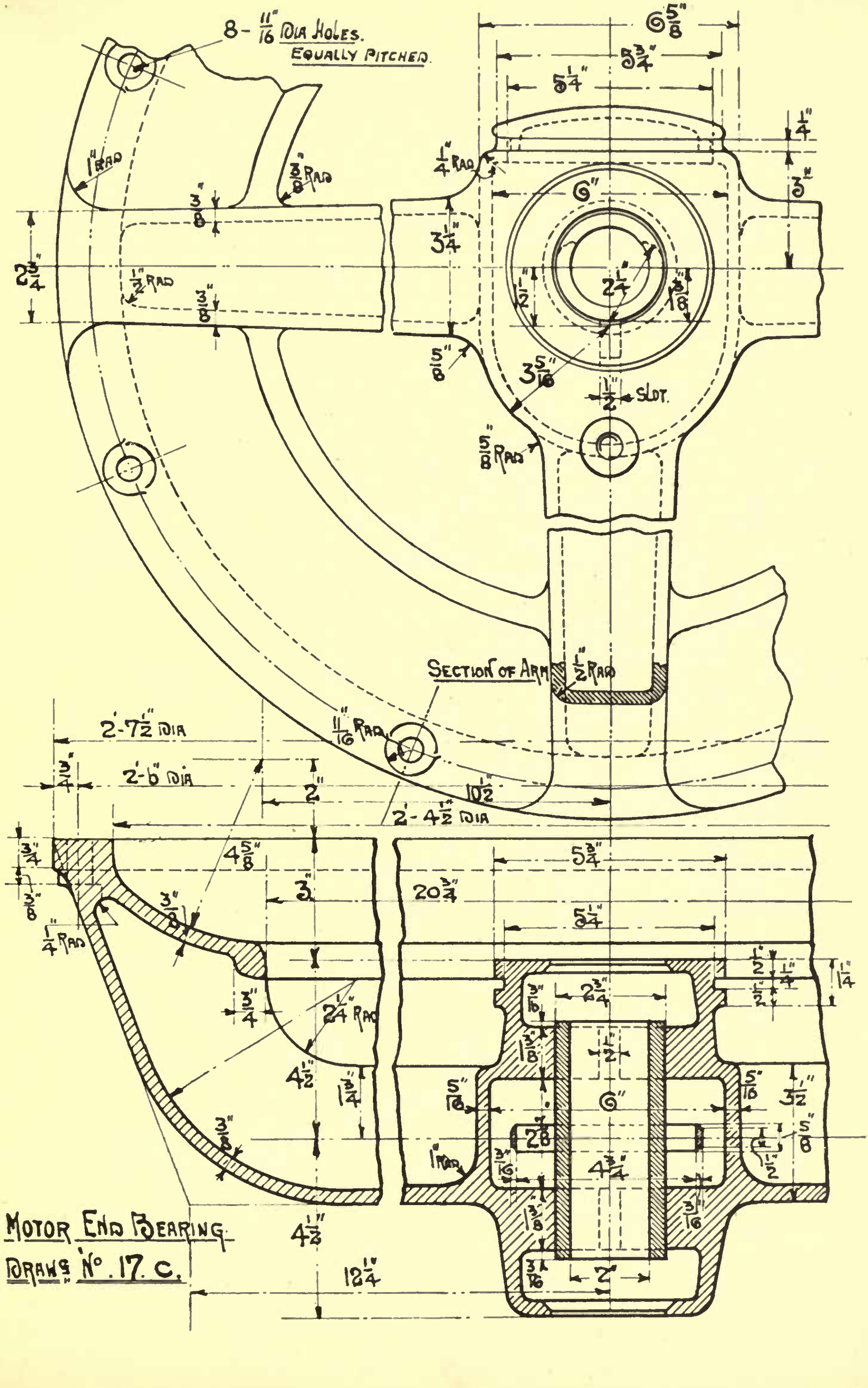
Fig. 74.—Motor End Bearing.

expanded to fit against this cone, and is drawn tight up to it by the union nut; the joint is made oil-tight by the mild-steel washer, bearing faces slightly rounded, bearing against the nut, and the flanged end of the pipe.

Draw to a scale of three-eighths full size the views shown, drawing in the whole of the end cover.

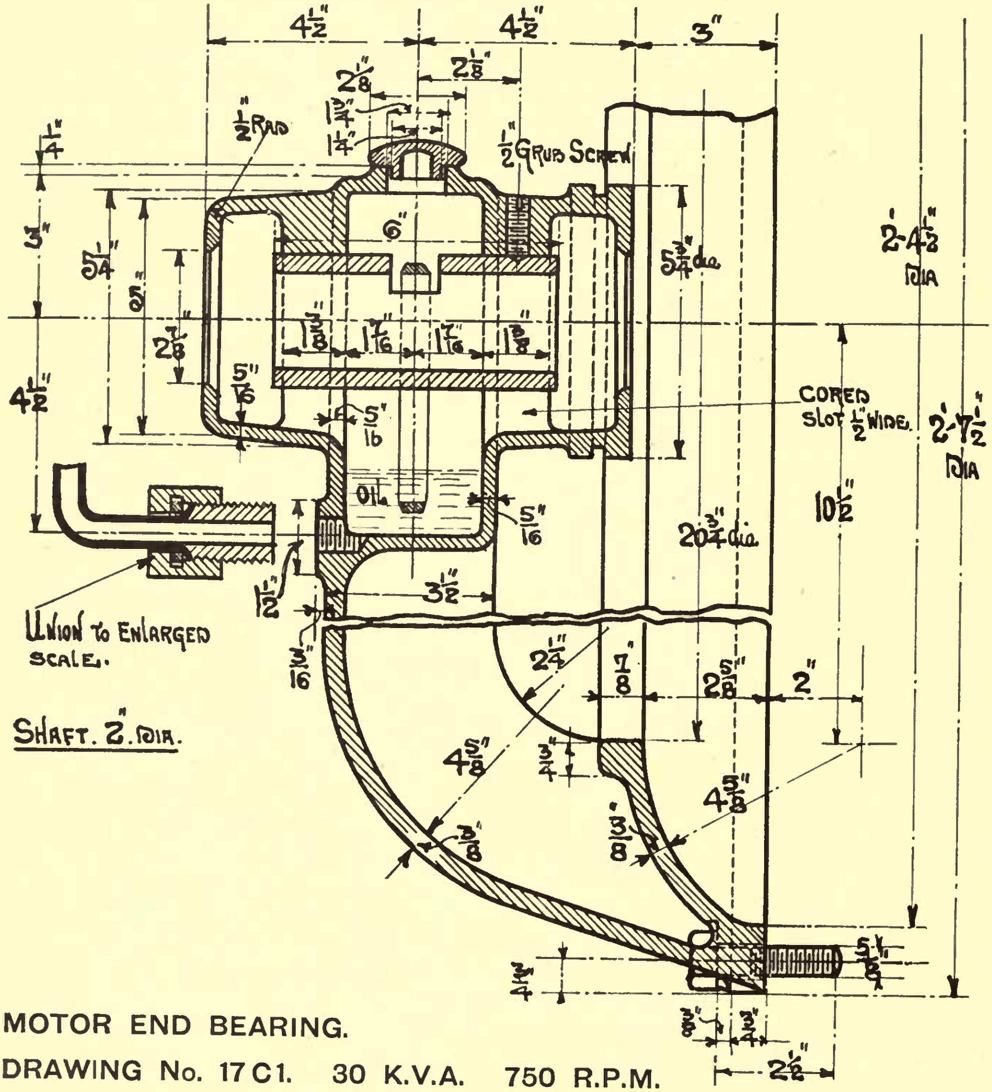
Fig. 74 gives an idea of the arrangement.

White Metal.—The friction in a bearing depends upon the composition and structure of the alloy, and the harder the metals in contact the lower the coefficient of friction, but the greater the tendency towards heating owing to


8 - 11/16" DIA HOLES.
EQUALLY PITCHED.
SECTION OF ARM
2'-7½" DIA
2'-6" DIA
2'-4½" DIA
SLOT.
MOTOR END BEARING
DRAWG No. 17 C.

the want of plasticity. Thus, for mild steel running on white metal the pressure may rise to 500 lbs. per square inch of projected area without undue heating. With a soft bearing metal the bearing must be sufficiently long to support the load without deformation. White metal does not cut the journal, but should the temperature of the bearing get fairly high owing to want of lubrication, the white metal melts, and tends to act as a lubricant, whereas a harder metal would seize on to the shaft. For high speeds white metal should always be used, and for split bearings the cap bolts should be locked.

There are many compositions of white metal, from true Babbitt's metal to



MOTOR END BEARING.

DRAWING No. 17C1. 30 K.V.A. 750 R.P.M.

simple lead-antimony alloys. A typical composition is: 55 parts of tin, 18 parts of antimony, 24 parts of lead, and 3 parts of copper. The use of lead makes the metal cheaper, and more easily melted and machined.

Example.—Explain how a bearing is lined or re-lined with white metal, noting how to prevent the metal sticking to the shaft or mandrel by the use of French chalk or oiled paper, how to prevent spluttering when pouring by warming up the castings until they stop sweating, and that the metal must be melted slowly and well stirred before pouring.

With good white metal and complete lubrication, the coefficient of friction μ is reduced to ·003 with a shaft surface speed of 5 feet per second.

Fitting of Shaft and Bearing.—The accuracy of the fit of a bearing to its shaft depends upon the time and skill expended upon bedding the bearing. The radius of the bearing being greater than the radius of the shaft, with a continuous oil film the nearest point of contact is roughly at an angle of 40 degrees with the vertical centre line, on the off side of the bearing, for a bearing carrying a vertical load. If perfectly fitted, the shaft, on first running, would grind out the bearing until these conditions obtained. Usually working fits allowing given variations are adopted. The shaft may have an exact diameter or may be under. The hole must at least be larger than the exact shaft diameter, but must not exceed a certain diameter. The allowances vary with the class of work. Thus, we have tables similar to following:—

Shaft Diameter.	Maximum.	1	2	3	4	5	6 inches
	Minimum.	·00175	·0025	·003	·0035	·00375	·004 under maximum.
Hole Diameter.	Minimum.	1·00175	2·0025	3·003	4·0035	5·00375	6·004
	Maximum.	1·0035	2·005	3·006	4·007	5·0075	6·008

Limit Gauges.—Explain, with sketches, the use of limit gauges in checking the maximum and minimum diameter of details which are to work together.

Journals are necked for the purpose of keeping the shaft in its place, and preventing great oil leakage from the free ends of the brass. The student should, from his own observations, make a table similar to the following, showing the relation between the shaft diameter and the radii of the neck.

Diameter of Shaft or Pin	1–1¾	2–3¼	3½–5½	6–9½	10 inches.
Radius of Shaft or Pin .	⅛	¼	⅜	½	¾ inch.
Radius of Bearing . .	$\frac{3}{16}$	⅜	½	⅝	⅞ inch.

FOOTSTEP BEARING.

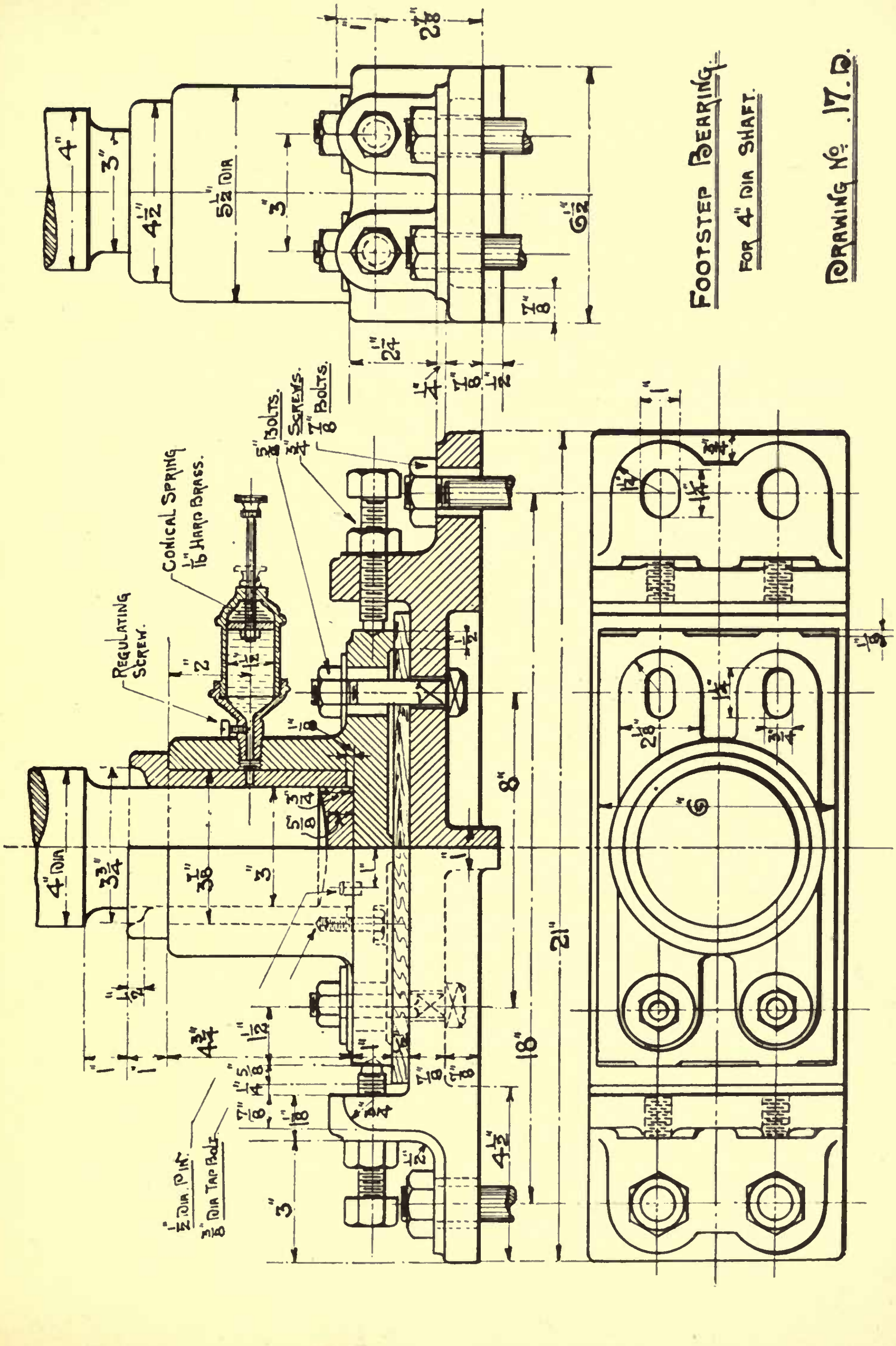
Drawing No. 17D.

ENERGY is often transmitted from one floor-level to another by means of a vertical shaft. To carry the weight of this shaft at its lower end becomes an important matter, and some form of footstep bearing is required. The greatest difficulty is that of keeping the bearing sufficiently well lubricated to prevent heating. In the example, the footstep casting of cast-iron supports the gun-metal bush, which is fixed in position, and prevented from rotating by the set screw. The end of the shaft is rounded, and bears on the phosphor-bronze disc, which is prevented from rotating by the steel pin. The bearing is lubricated by the spring of the Stauffer lubricator forcing out the grease into the bearing, the outlet being regulated by the small screw shown. The footstep is supported on a hardwood packing, and is adjustable on the sole-plate by the four screws indicated, the sole-plate being held down to its foundation by short rag bolts of the type indicated in Drawing No. 12, Card No. 4.

Draw to a scale of half full size, finishing off completely as a general arrangement, the three views shown.

Examples—

1. Make detail drawings fully dimensioned of all the details in the above drawing.
2. The total weight of the above shaft and its accessories, all carried by the pivot shown, is 1550 lbs. What is this, expressed in lbs. per square inch of bearing area ?
3. The shaft makes 300 revolutions per minute. What is the speed in feet per minute on a circle two-thirds the pivot diameter ?
4. Make a sketch of a footstep bearing in which the disc or discs can be renewed without moving the shaft.


FOOTSTEP BEARING.
FOR 4" DIA SHAFT.
DRAWING No. 17. D.
REGULATING SCREW.
CONICAL SPRING
1/16" HARD BRASS.
5/8" BOLTS.
3/4" SCREWS.
7/8" BOLTS.
1/2" DIA PIN.
3/8" DIA TAP BOLT.
5 1/2" DIA
4" DIA
21"
18"
8"

BALL BEARINGS.

A BODY may move relative to another either by sliding or by rolling, and we have sliding friction and rolling friction. The resistance to motion is very much reduced when rollers are put between the moving surfaces. The rollers may be long cylinders (roller bearings) or spheres (ball bearings). If a hard disc of metal truly machined be rolled along a machined plate of metal, on making one complete revolution the disc does not travel a distance equal to its circumference, as there is a certain amount of slip, due to the disc indenting the surface. The slip becomes smaller as the diameter of the disc increases. Lubrication of roller and ball bearings is necessary, and a heavy grease is better than oil.

The three types of ball bearing are: **Radial**, carrying a load perpendicular to the axis; **Thrust**, carrying a load parallel to the axis; and **Angular**, the load being at an angle to the shaft axis, and is taken as the resultant of a radial and a thrust load.

Drawing No. 17E.

Thrust Ball Bearing, as applied to a steam engine governor, is shown. The object of the governor being to regulate and keep the speed of the engine constant as the load varies, its regulation is seriously affected by friction at the joints and on the moving parts. The up-and-down motion due to change of speed is transmitted to the end of the lever operating the throttle valve through the bearing given.

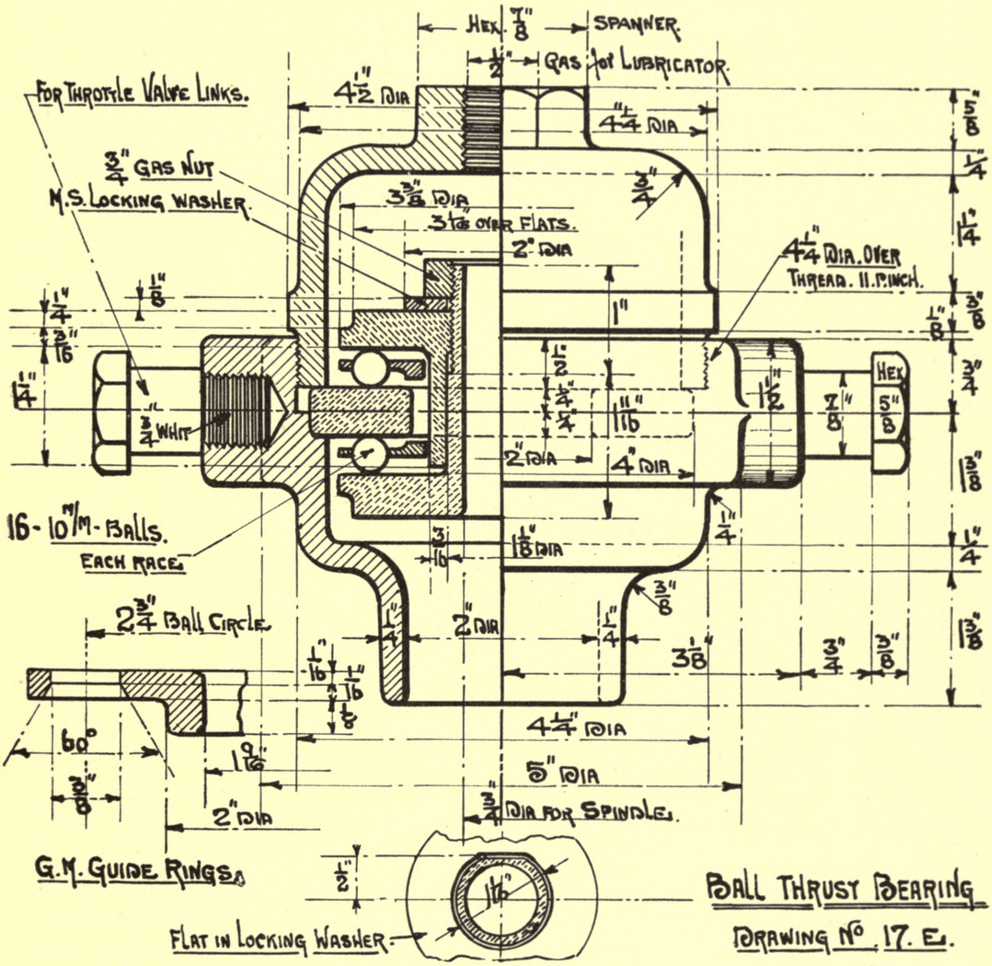
Draw to a scale of full size a sectional elevation, an outside elevation, and a plan.

For a thrust bearing the loading capacity is proportional to the square of the ball diameter, and depends greatly upon the speed. Thus a bearing suitable for the end of the shaft, Drawing No. 17D, 3 inches diameter, has ten balls, each 1 inch diameter. The crushing load of one ball is 140,000 lbs., and the maximum safe working load, *i.e.* that for a bearing just or occasionally turning, is 21,100 lbs. per ball. As the speed rises the working load diminishes.

Revolutions per minute.	Just turning.	50	100	150	200	300	500	750	1000	1500
Working load, lbs.	21,100	9400	6700	5500	4700	3760	3000	2400	2100	1700

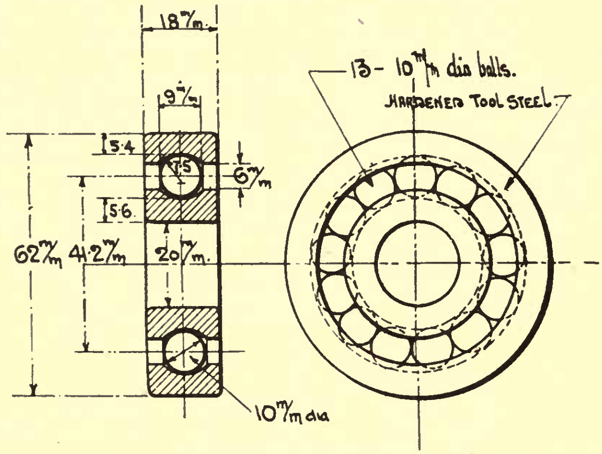
A grooved race carries more than a straight race. With the balls in a cage—

that is, using guide-rings—if the pressure becomes excessive, the balls exert a pressure outwards on these rings. Care must be taken that the cage floats on the balls, and does not rub on the shaft or discs.



RADIAL BALL BEARING.

ANOTHER type of ball bearing is that carrying a load perpendicular to the shaft axis, and called a journal or radial bearing. It is shown in fig. 75. The speed does not affect the load-carrying capacity in this type, but dust and dirt must be kept out by fixing suitable grease-rings or leather washers. The balls may fill the row or may be supported by guide-rings.



SINGLE FULL ROW BALL JOURNAL BEARING

FIG. 75.

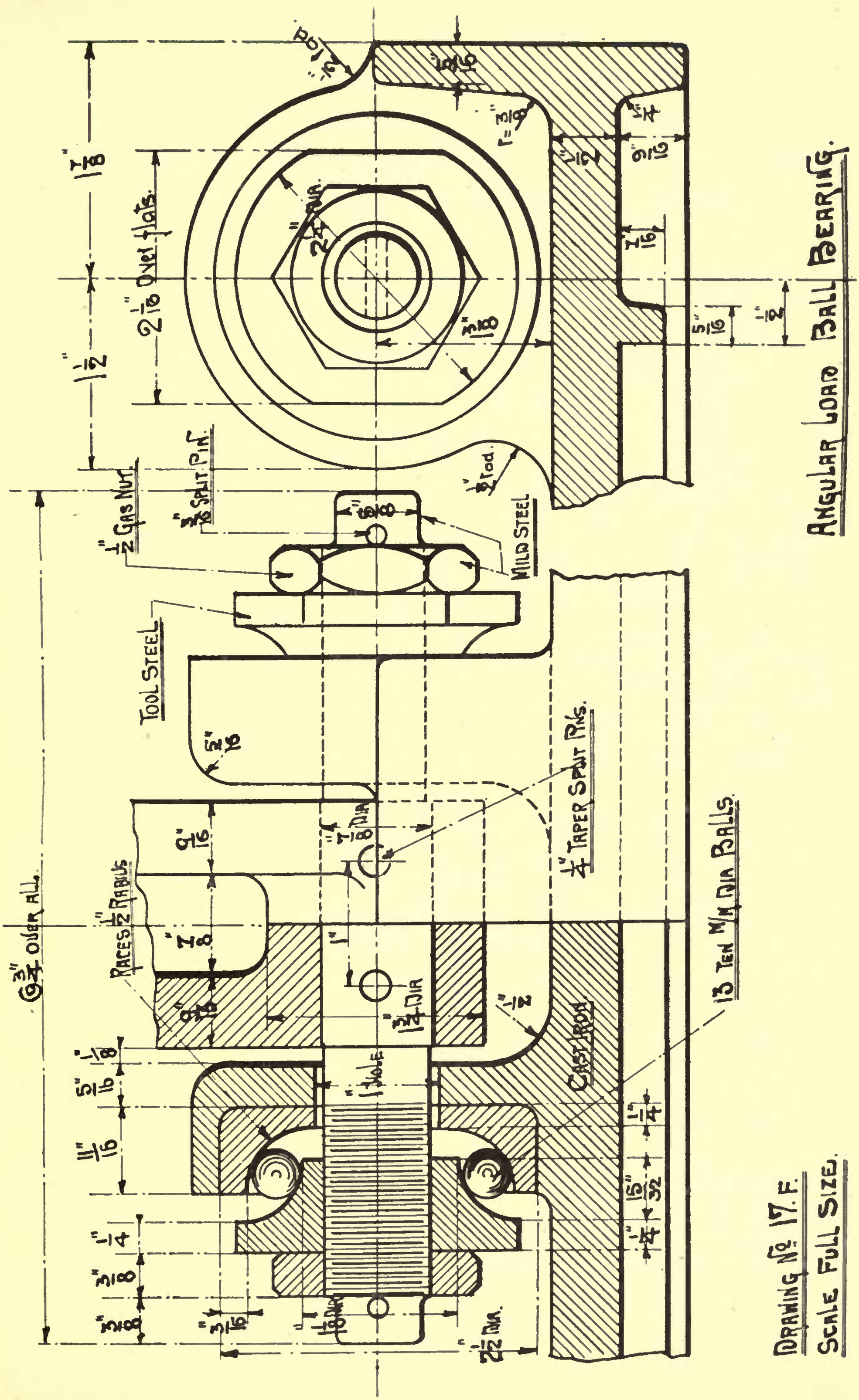
Drawing No. 17F.

Angular load bearing may be made of a combined thrust and radial bearing, or may be as shown in Drawing 17F. The cast-iron base disc carries another similar spindle; to each is pinned a governor, ball or weight. The disc rotates horizontally, and the spindles oscillate as the speed of rotation changes. The ball motion is transmitted to the throttle valve lever by the main governor spindle, which is attached to the ball thrust bearing already drawn out.

Draw to a scale of full size a sectional elevation, an outside end elevation, and a plan.

The satisfactory use of ball bearings is obtained only by care and experience. For durability, the dimensions of the rings, balls, and curve radii are important; also the material, hardening, grinding, and polishing must be of the best. The balls in any one bearing should not differ in diameter by more than one ten-thousandth part of an inch, and the working parts should be of crucible cast steel.

To get perfect rolling, the contact points of the balls and races in angular


ANGULAR LOAD BALL BEARING.
DRAWING No. 17. F.
SCALE FULL SIZE.
6 3/4" OVER ALL.
2 1/16" Over Flats.
1/2" GAS NUT
3/16" SPLIT PIN.
MILD STEEL
TOOL STEEL
1/4" TAPER SPLIT PINS.
RACES 1/2" RADIUS
CAST IRON
13 TEN M/M DIA BALLS.

load bearings should form a cone of revolution having its apex on the shaft centre line.

Friction, μ, for a journal bearing varies from ·001 to ·01; for good working bearings μ does not exceed ·002, and the energy lost in friction is reduced 50 per cent. compared with the best sliding journals (refer to page 135).

Example.—Sketch a journal bearing in which the balls are held in a gun-metal cage, and explain how the balls are put in position, and the tongues of the cage bent over.

Lubrication of Bearings.—The first essential is that a good lubricant should be used, and to be satisfactory it should have the following properties:—

It must be viscous and maintain its viscosity at fairly high temperatures.
It should not evaporate rapidly at working temperatures.
Vaporised oil should only be inflammable at high temperature (300° F.).
It should not oxidise on exposure to air.
It should not oxidise the bearing surfaces.
It should possess a good affinity for the metallic bearing surfaces.

Application of Lubricant.—To make sure that lubrication is continuous and satisfactory for shafts running at high speeds, **forced** lubrication is used—that is, oil is forced through the bearings by means of a pump. For engine and dynamo work the usual pressure is 14 lbs. per square inch. Should this be exceeded, a relief valve is provided to allow the oil to leak away. For high-speed turbine footstep bearings, the pressure is 200 lbs. per square inch, and special arrangements are made that the oil supply does not fall below this. To prevent undue heating of large bearings, the heat generated is carried away by a system of water cooling instead of relying upon natural radiation. For most industrial work, however, the lubricant passes to the bearing by gravity.

Syphon Lubricator (fig. 76).—An oil-well is provided, and from it to the oil-hole is a length of wool or wick. Oil is syphoned from the well, and

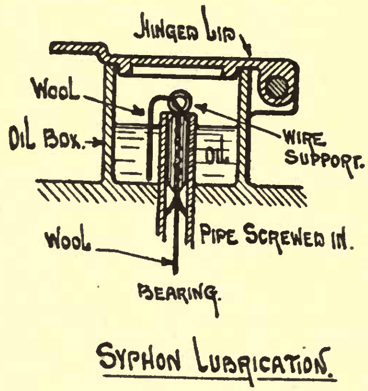


Fig. 76.

drops into the oil-hole at a regular rate by the action of the oil creeping up the wick.

Example.—Take a few threads of wool or worsted, twist them together, wet them, and hang over the edge of a pot almost filled with water, so that

the end hanging over is at a lower level than that within the pot. Note the action of the wool in making the water drip out of the pot.

Needle Lubricator (fig. 77). — The spindle or needle rests on the shaft, and is vibrated about by the vibration of the shaft, the oil leaking in between the spindle and the wood cork, and dripping on to the journal at a steady rate. In bushed bearings, to prevent the oil leaking between the bush and the cap, a tube should be fitted to conduct the oil to the journal. The lubricator feeds only when the shaft is running. When stopped, capillary action prevents the oil flowing down the needle.

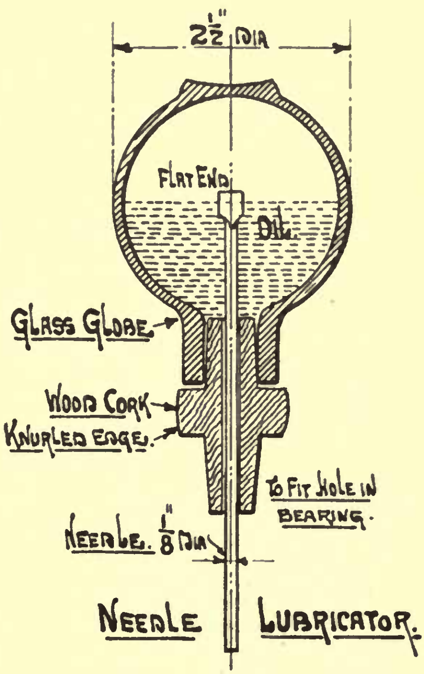


FIG. 77.

Examples—

1. When fixing up line shafting, what construction allows a pedestal to be adjusted to the shaft centre line?
2. State under what conditions (1) hangers, (2) wall boxes, and (3) end wall brackets are used. Give a rough freehand sketch with leading dimensions for each.
3. Sketch and explain the use of an angle pedestal.
4. The distance between centres of bearings for line shafting is determined by their stiffness, or tendency to whip. In the formula

$$\text{Bearing centres} = \text{constant}\ \sqrt{\text{shaft diameter}^2} = \text{feet},$$

find the constant. Centres, 8 feet; shaft, mild steel, $2\frac{1}{2}$ inches diameter.
5. *Work lost by Friction in a Bearing.*—In the case of line shafting, the load on the bearings is due to weight of shafting, weight of couplings and pulleys, and pull of the belts. To reduce this, the belts should if possible pull on the shaft in opposite directions. The total load rarely exceeds 90 lbs. per square inch of projected area, that is, length $\times$ diameter.

A shaft $2\frac{1}{2}$ inches diameter, making 300 revs. per minute, has bearings 7 inches long pitched 8 feet centres. Total load on one bearing at driving end is 680 lbs. Taking the coefficient of friction $\mu = \cdot 02$, what horse-power is lost in the one bearing in overcoming friction?
6. Pedestals or plummer blocks for shafts 4 inches diameter and over are fitted with four cap bolts, and four sole-plate or base bolts.
7. To prevent the oil leaking from the bearing and running and dripping all over the place, oil-catchers or trays are fitted. Sketch roughly a pedestal showing such trays.

ADJUSTABLE VEE PACKING BLOCK.

Drawing No. 18.

ADJUSTABLE vee packing blocks are used for supporting and setting up round details ready for machining, when the latter require to be some distance above the machine table.

Such a block consists of (fig. 78) a cast-iron base or foot, machined on the top and bottom faces, smooth-bored to take the mild steel nut, and fitted with set screw for locking this nut. The mild-steel nut is supported by, and turns freely in, the top of the body casting, it is bored and threaded to carry the vee block, which is made of mild steel, the stem being screwed with a square thread 4 threads per inch to fit the nut.

FIG 78.—Adjustable Vee Block.

The job rests in the vee, and for adjustments of height the nut is turned by means of its hexagon head and a spanner. When the job is set correctly, the nut is prevented from turning by gripping it with the small locking screw.

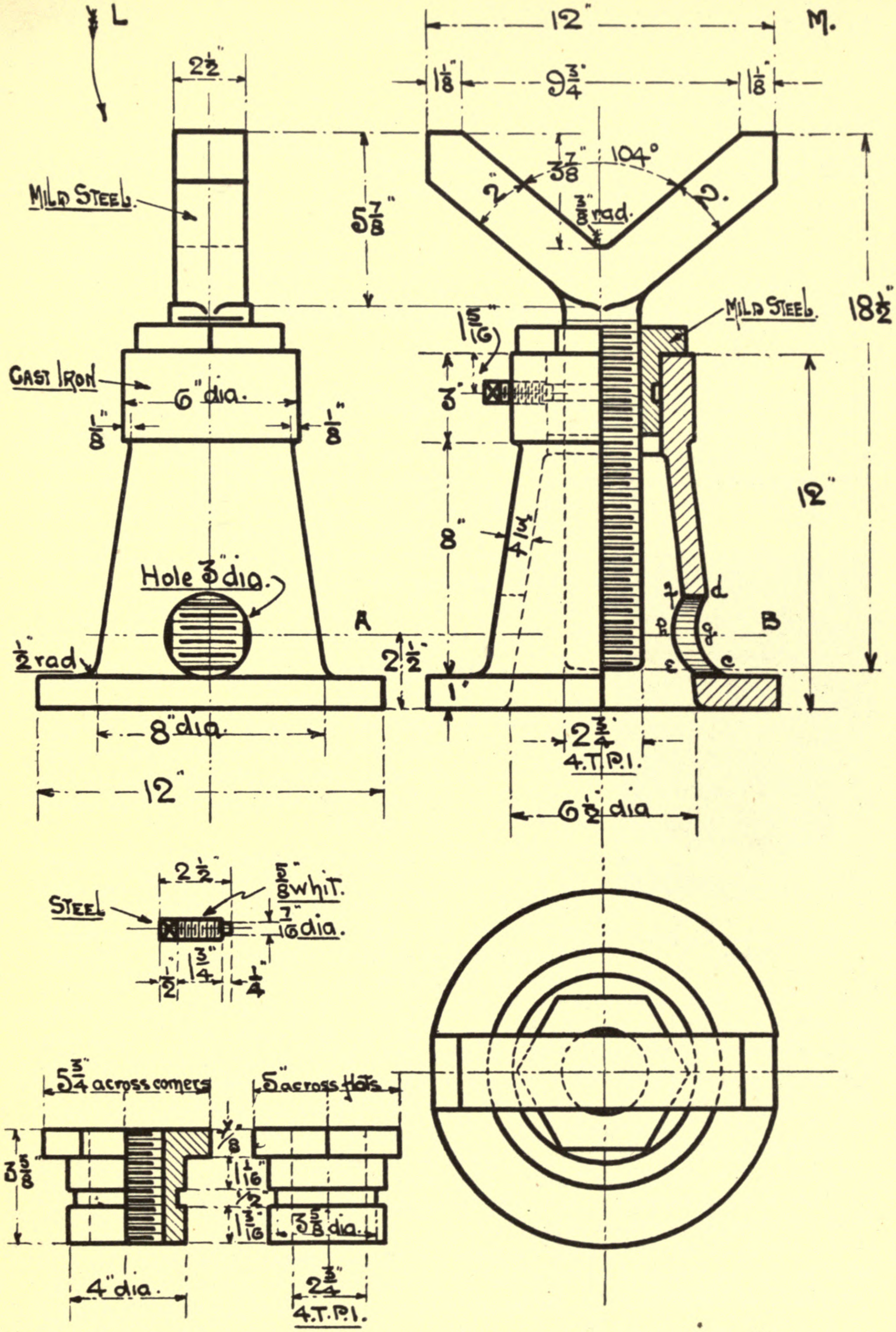
Draw—

1. The two elevations as shown.
2. Under view L, a plan in correct projection looking in direction of arrow.
3. Under view M, a sectional plan on the plane AB, considering the upper part removed.

Note.—Do not draw the curves *cd*, *ef* in the sectional elevation until the sectional plan has been drawn. From this the points *g*, *h* are obtained by projection at once. Parallel sections taken above and below the plane AB enable other points on the curves to be found, joining which gives the true projection of the hole.

Question.—What is the object of the hole through the bottom of the cast-iron base?

Example.—Describe, with sketches, the pattern and core box from which the above cast-iron base would be made. State how much of an allowance for machining would be given on the base, top face, and in the cored hole.



DRAWING No. 18.

SCALE HALF FULL SIZE.

ADJUSTABLE VEE PACKING BLOCK.

ADJUSTABLE SCREW PACKING.

Drawing No. 18A.

THE drawing illustrates the use of a square thread for the moving of a considerable load. It is used on the bed of a planing or boring machine, to assist in adjusting the job, also to support and stiffen up any parts not otherwise supported, so as to prevent undue warping during machining. It consists of (fig. 79) a loose mild-steel cap fitting on the spherical head of the screw, so that it can adjust itself to slight inclinations of the piece being machined, and a square-thread screw, carrying the cap and supported in a cast-iron nut formed as shown.

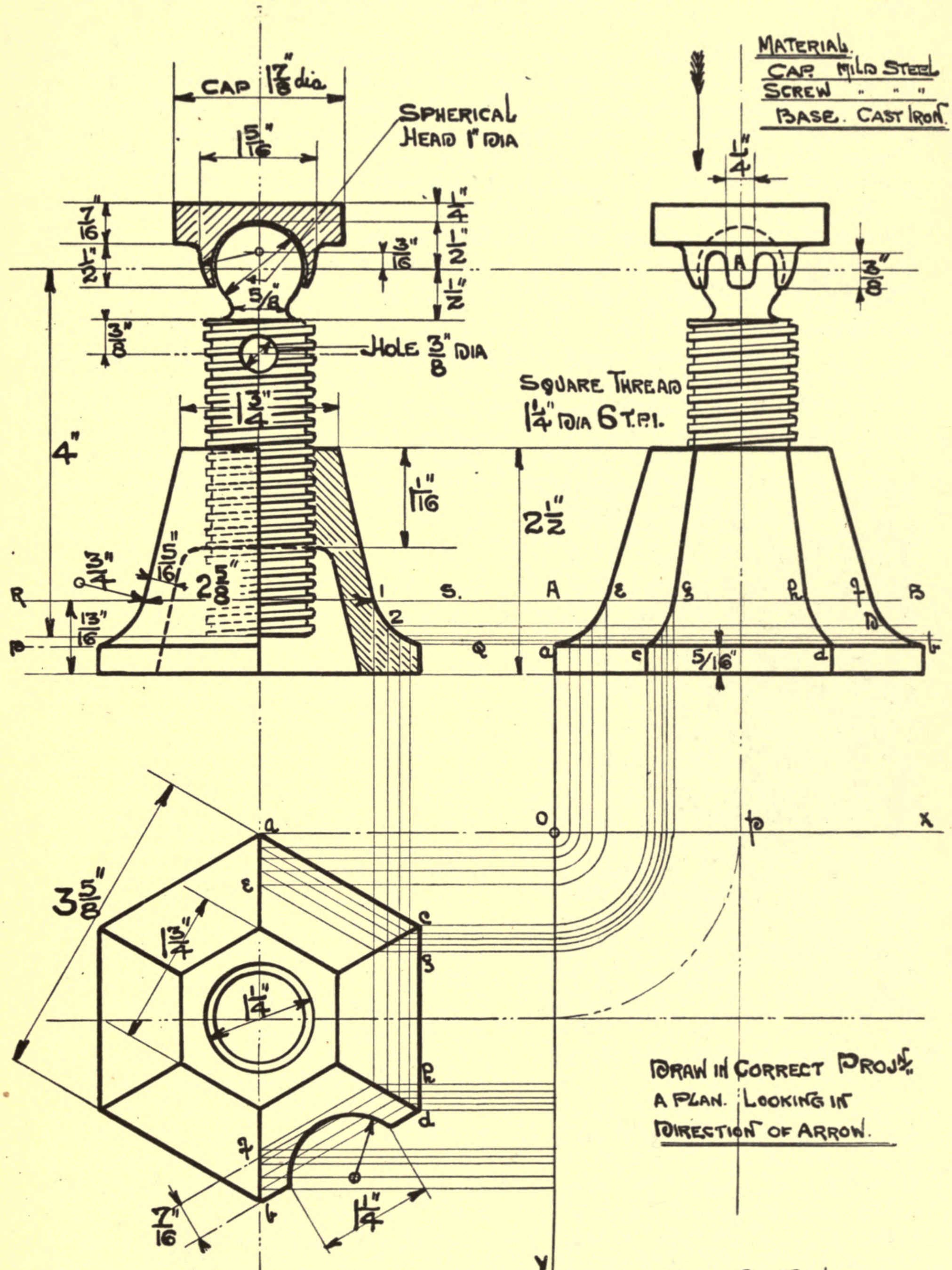
FIG. 79.—Adjustable Screw Packing.

Draw to a scale of full size—

1. The general arrangement shown, adding the plan required.
2. A detail of the cast-iron body or nut, fully dimensioned, showing an outside elevation, section, plan looking on top, plan of under side, and a section across the line AB.

Note.—The cap swivels loosely on the ball-head of the screw. To prevent it falling off, the ears marked A are formed as a cylindrical piece parallel to the axis, the slots cut out, and when assembled the ears knocked over the spherical head by the round or riveting head of a hammer. The cast-iron base which forms the nut has its interior of round conical form, the outside being hexagonal, tapering off to the top, the flat side in each case being filleted off at the base, with a fillet $\frac{3}{4}$ inch radius, as shown in the section. The projection of the corners formed by the junction of these face fillets, as shown at D in the outside side elevation, would ordinarily be drawn in roughly by eye. The correct method of producing the curve geometrically is:—

First take a horizontal cutting plane or surface PQ. Assume the casting parted into two across this plane. Remove the portion above PQ, and draw the plan of what remains. It is the hexagon distance across flats, $3\frac{5}{8}$ inches. To draw the side elevation of this hexagon:—*ab* is the distance across corners, *cd* the width of the face, both measured from the plan. The axes OX, OY indicate the correct way to turn the projection back, so as to form the side elevation. If the centre line for the side elevation has already been drawn in,



DRAWING No. 18. A.
SCALE FULL SIZE.

MACHINE TOOLS.
SCREW JACK FOR PACKING

the point O in OX must be taken such that *po* equals half *ab*; otherwise the point *o* may be taken at any convenient position along the horizontal OX.

Secondly, take a horizontal plane RS. Assume the casting parted as before and the top removed. To draw the side elevation of this hexagon:—*ef* is the distance across corners, *gh* the width of the face, both measured from the plan and transferred direct, or swung round by means of the axes OX, OY.

Similarly, by taking further horizontal cutting planes between the planes RS and PQ we can obtain other points on the required curves *ae, cg, dh,* and *bf*. Joining these neatly by hand, or by the nearest approximate circle or a pattern (French curve), we show the required intersections of the face fillets.

Examples—

1. Through what height is the cap of the jack raised for five complete turns of the screw?
2. With a pull of 20 lbs. applied on a bar at a radius of 12 inches from the axis of the screw, what total force will the cap exert on the job: (1) if we neglect any loss due to the transmission of the force through the parts of the jack? (2) if we take the efficiency of the jack as 35 per cent.?

MACHINE VICE.

Drawing No. 19.

Draw to a scale of three-quarters full size a general arrangement from the details given, showing a plan, a side elevation, and an end elevation looking in the direction of the arrow Y, one side of the centre line being an outside view, the other side a section taken along the plane CD.

Indicate by red lines along the face all the parts which require machining.

Fig. 80 illustrates the use of the vice. It is bolted down to the bed or table of the milling machine, and small jobs are securely held in it during the process of machining. It is much more handy, convenient, and economical as compared with the clamping of the job direct to the machine table.

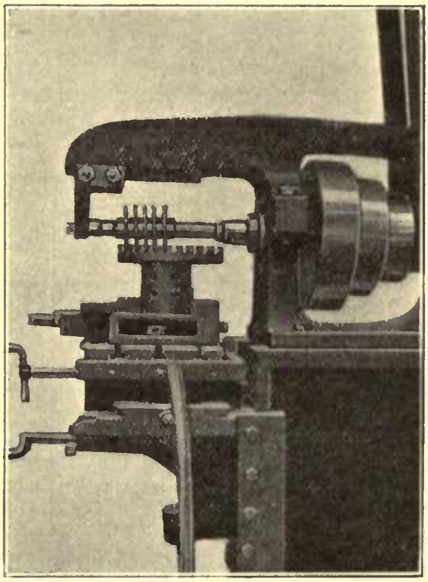
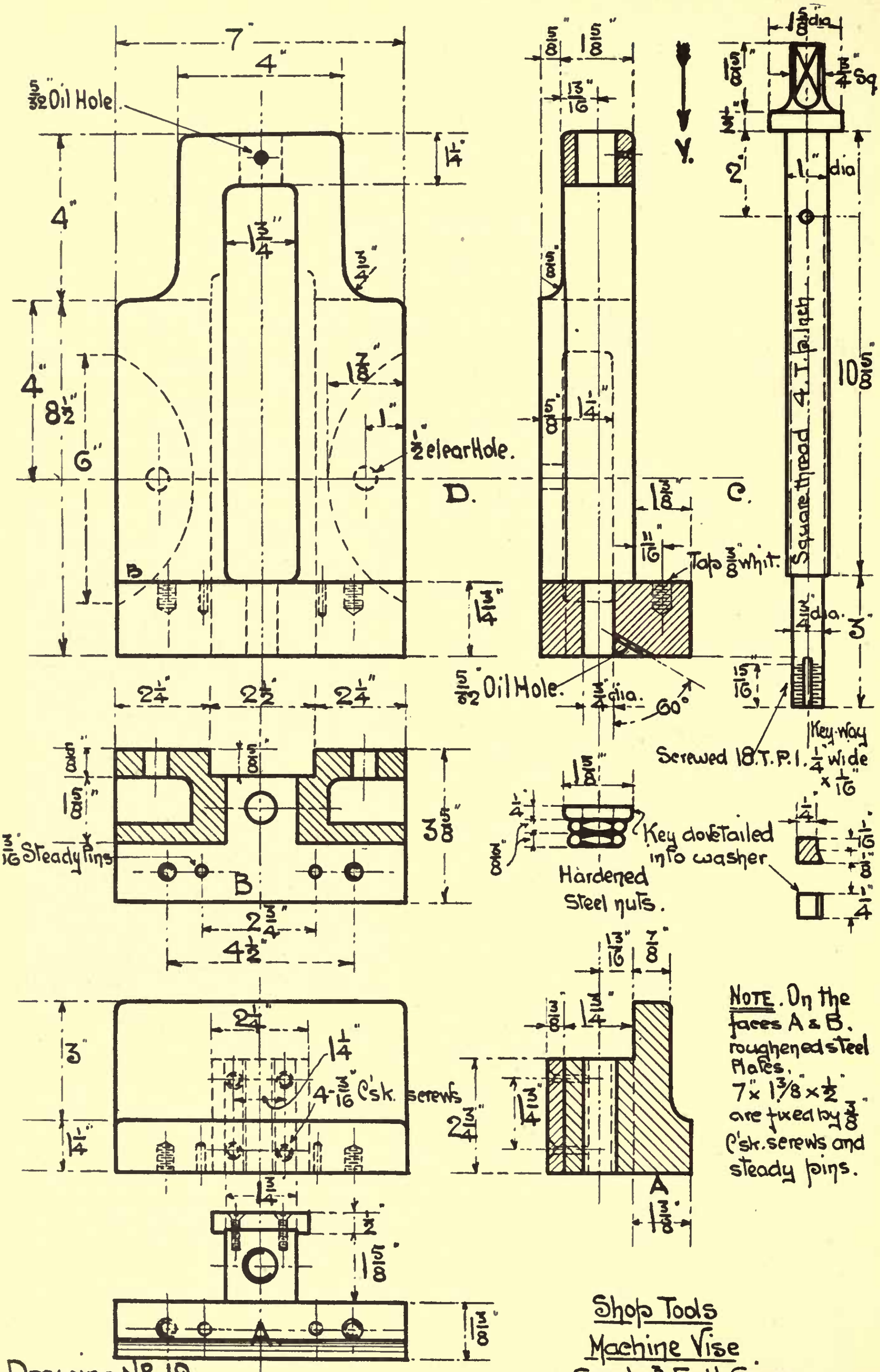


FIG. 80.—Showing Machine Vice in use.

The main casting is of cast-iron, planed on the bottom and top, the slot also being machined out. The clearance holes for bolting it down to the machine bed by tee-head bolts are drilled. The screw bearing holes are bored so as to be exactly in line.

The adjustable jaw is of cast-iron, the under face, top, and sides of the projection forming the nut being machined a good fit to the slot and face of the main casting, and the nut being cut with a thread to suit the screw of 4 threads per inch. The bottom bearing plate, which slides against the under side of the recess in the main casting, is fixed to the nut by four round flat-head screws. It is machined to fit soundly against the bottom of the nut, and its side flanges to be a good working fit against the sliding surface. The mild-steel screw is cut with a standard square thread 4 T.P.I., the end of which is shown by the small circle on the screw detail. It is turned by aid of a box-key or spanner (fig. 81) fitting on the square shank end, and moves the adjustable jaw by means of its nut, the screw itself being held free to rotate between the fixed collar and the end washer, which is made to turn with the screw by means of the small key which is dovetailed into it and fits into a keyway in the end of the spindle. This end washer is fixed in position by means of the two hardened steel lock-nuts.

To grip the job securely, the jaws A and B are faced with hardened steel



Drawing No. 19.

Shop Tools
Machine Vise
Scale 3/4 Full Size.

plates $\frac{1}{2}$ inch thick. To prevent the job twisting, they are roughened by diagonal cross-hatchings, and are fixed to the cast-iron faces by means of counter-

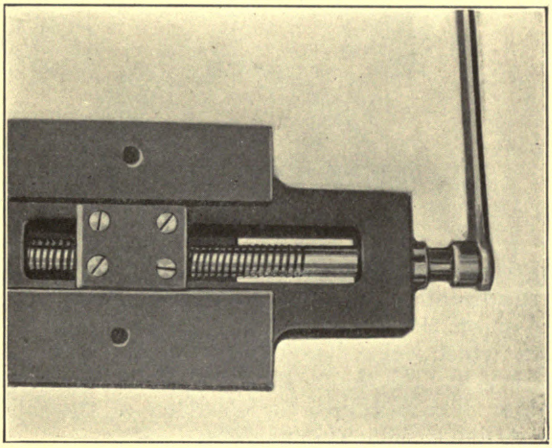


FIG. 81.—Machine Vice (under view).

sunk screws, heads sunk $\frac{1}{32}$ inch below surface, and also steady pins to obtain rigidity and enable them to be replaced, after removal for re-cutting, in their old exact positions.

The details given are:—

Main casting.
Screw with key-nuts and washer.
Adjustable jaw with bottom bearing plate.

Do not draw the separate details, but the general arrangement asked for and illustrated by fig. 82.

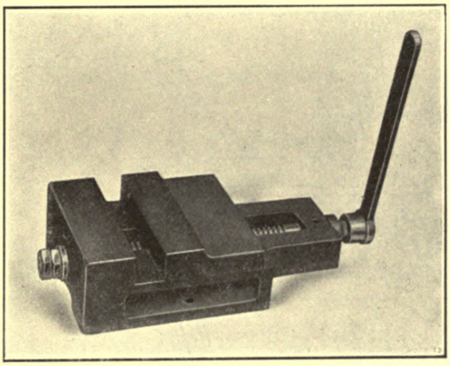


FIG. 82.—Machine Vice.

Example.—Sketch in good proportion, complete with all dimensions, a box-key or spanner suitable for tightening up the vice.

STEAM-PIPE EXPANSION JOINT.

Drawing No. 20.

WHEN arranging steam mains provision must be made for expansion and contraction and the draining away of water of condensation, if accidents are to be avoided. The object of this steam-pipe expansion joint is to allow for the changes in length which take place, due to changes of steam pressure and temperature, and it is suitable for a short length of piping connecting a boiler direct to the engine. The flexibility or elasticity of the copper takes up the small alterations in length which occur.

It consists of a **U**-section copper ring, with cast-iron flanges brazed on, fixed by bolts between two flanges in the main steam-pipe, which is of cast-iron, the joint at their flanges being made steam-tight by means of a corrugated plate made from sheet brass $\frac{1}{64}$th inch thick.

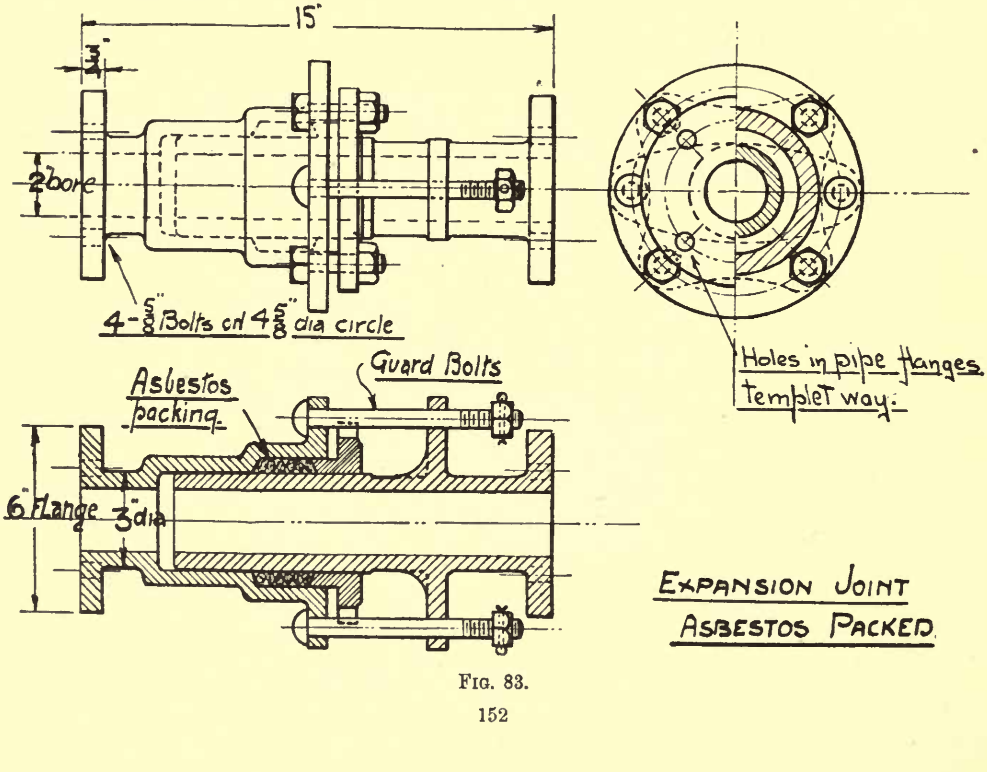
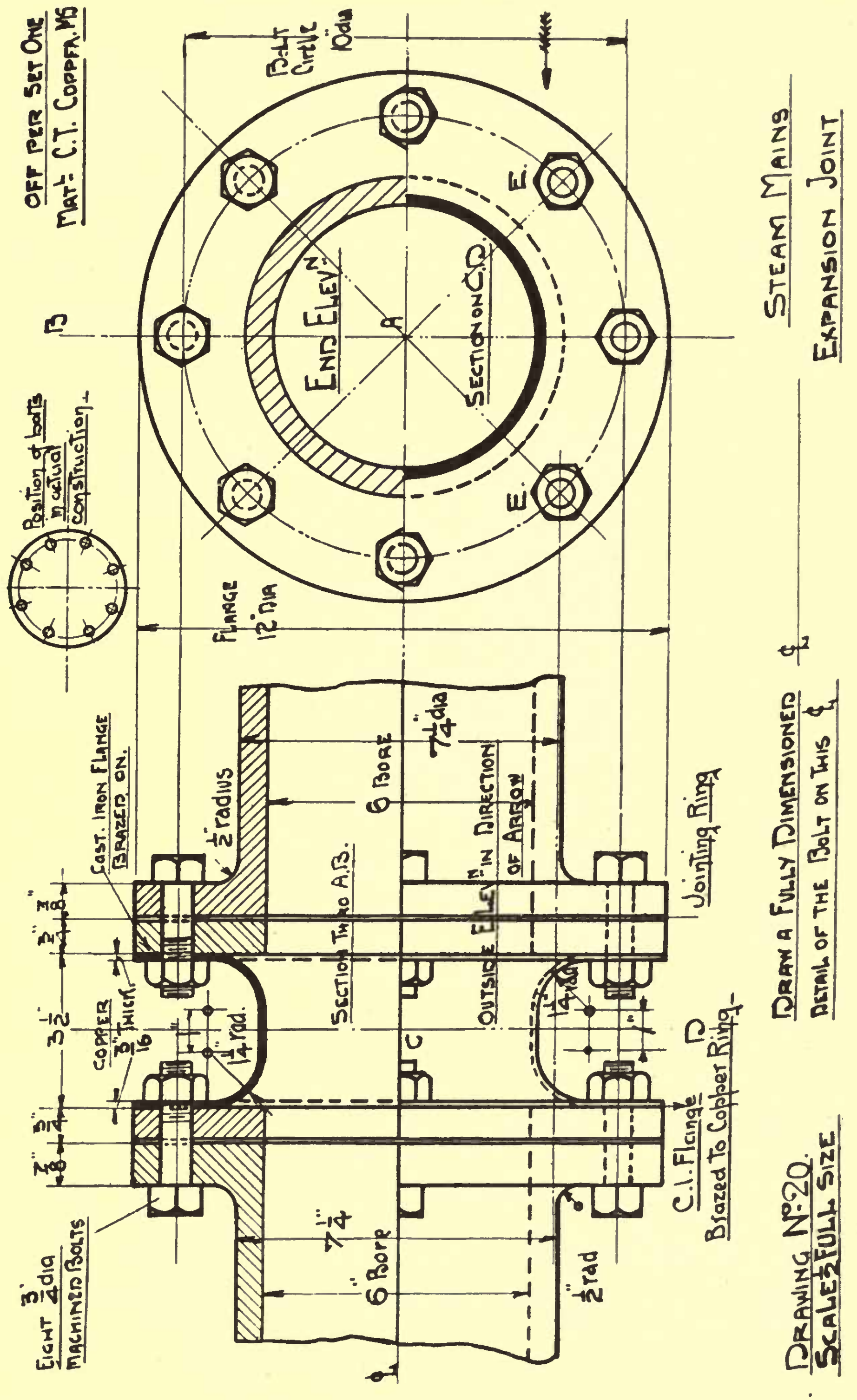


FIG. 83.


OFF PER SET ONE
MATL: C.T. COPPR. MS
Bolt Circle 10" dia
END ELEVN
SECTION ON C.D.
A
B
E.
E.
Position of bolts in actual construction
FLANGE 12" DIA
STEAM MAINS
EXPANSION JOINT
CAST. IRON FLANGE BRAZED ON.
½" radius
6 BORE
7¼" dia
SECTION THRO A.B.
OUTSIDE ELEVN IN DIRECTION OF ARROW
C
D
Jointing Ring
COPPER 3/16" THICK
1¼ rad.
C.I. Flange Brazed to Copper Ring
EIGHT ¾" dia MACHINED BOLTS
½" rad
DRAW A FULLY DIMENSIONED DETAIL OF THE BOLT ON THIS ℄
DRAWING No 20.
SCALE ½ FULL SIZE

Draw to a scale of half full size—

Front elevation, half in outside view, half in section.
End elevation.
Section on the plane CD.

Give a full-size detail of the bolt: width across flats, 1·3 inches; head, $\frac{5}{8}$ inch thick; 10 threads per inch.

In actual erection, the bolts would not come on the horizontal or vertical centre lines, but as indicated in the small sketch—that is, bolts would be pitched off the vertical centre line.

In the outside front elevation the two bolts E, E are not projected, in order to show the detail more clearly. They should, however, be filled in, in correct projection, from the end elevation.

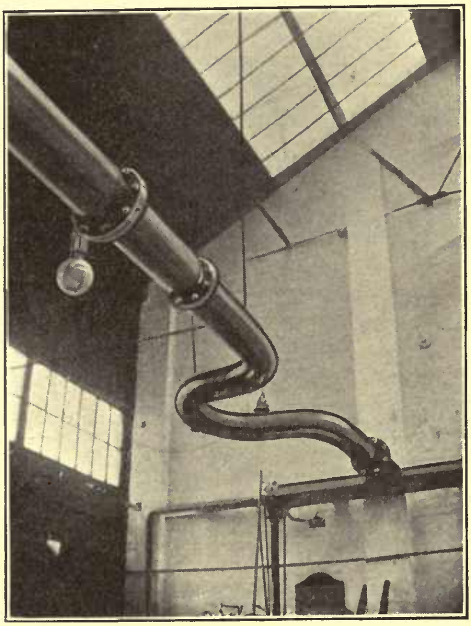


FIG. 84.—Steel Bend.

A two-face view of the bolt-heads is given. Often three-face views of hexagon heads and nuts are drawn, independent of correct projection, so that a two-face view will not be mistaken for a square head or nut.

The example drawn is only suitable for short lengths of piping. For cast-iron pipes of small diameter, carrying moderate pressures, but of considerable length, cast-iron expansion sockets as shown in fig. 83 are used. To prevent the sliding pieces rusting together, they are subjected to the Barff process, which protects cast-iron against rusting. For pipes of larger diameter, gun-metal sleeves are used. The holes in pipe flanges are arranged templet way, which permits of pipes being turned at right angles without bolt-hole difficulties being met with.

For pipes of larger diameter and higher pressures, expansion bends (fig. 84 and fig. 85) are used, and where space permits these bends should be horizontal and not vertical. They are made of mild steel or copper. At temperatures ordinarily met with in practice cast-steel is not affected by the temperature. Mild steel is preferred to copper because of its better welding

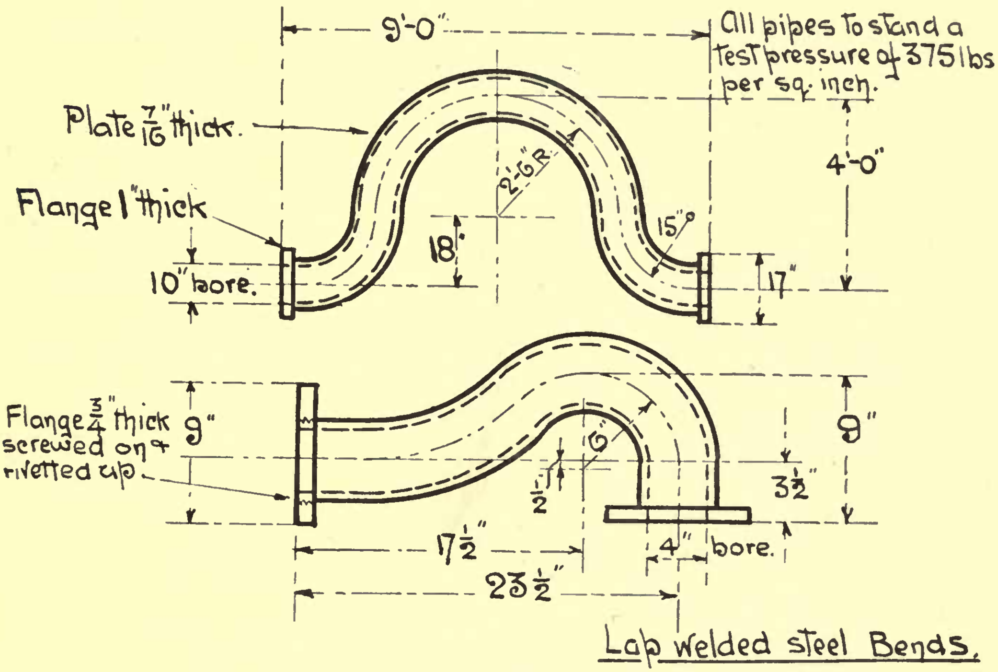


Fig. 85.

properties. At temperatures in the neighbourhood of 400° F. the elasticity of copper begins to diminish, and above 500° F. copper becomes unreliable. The mild-steel pipes are lap-welded and made from boiler-plate steel.

Examples—

1. Steam generated in the boiler is transmitted to the engine through a range of piping, or when used for heating is conducted round the buildings in pipes. Heat applied to metallic bodies, in general, causes them to increase their dimensions. Pipes used for such purposes change their length as the pressure, and therefore the temperature, of the steam in them changes. Unless provision is made so that these changes can take place, the forces brought into play will cause damage to the pipes or buildings.

   Example.—A wrought-iron steam main is 480 inches long, and the steam pressure in it changes from 5 to 150 lbs. per square inch. By how much does its length increase?

   Temperature of steam at 5 lbs., 228° F.; at 150 lbs., 370·8° F.

Wrought-iron increases in length by (·00000633 × length) for every 1° F. of temperature change.

Increase of length = coefficient of expansion × length × temperature change

$$= \cdot 00000633 \times 480 \times (370 \cdot 8 - 228)$$
$$= \cdot 434, \text{ say } \tfrac{1}{2} \text{ inch.}$$

The coefficient of linear expansion is a number expressing the ratio $\dfrac{\text{increase of length}}{\text{original length}}$ for 1° F. of temperature change.

The following table gives the values most often required:—

Material . . .	Cast Iron.	Wrought Iron.	Mild Steel.	Copper.
Coefficient of linear expansion	·00000589	·00000633	·00000734	·00000932

2. Describe, with sketches, and explain the use of materials such as rubber insertion, corrugated brass, millboard-woven wire, to make a tight joint between steam flanges.
3. What is meant by brazing? Describe the process of brazing a flange on a pipe, and give roughly the temperatures at which the brazing metal, the flange, and the metal of the pipe will begin to melt.
4. Steam-pipe covering. To prevent loss of heat by radiation from a pipe carrying steam, it is covered with some non-conducting material. State what materials are commonly used, how they are applied, and how they are held in position.
5. Under what conditions is it necessary to use studs instead of bolts for a flanged joint?
6. What is the pitch of the bolts along the bolt circle, in terms of the bolt diameter in Drawing No. 20? In calculating the bolt diameter, the steam pressure is taken as acting on the area of a circle touching the inner edges of the bolt-holes.

HYDRAULIC PIPE JOINTS.

Drawing No. 20A.

ONE of the chief difficulties in connection with the hydraulic transmission of energy is that of preventing leakage of water from the various joints in the distribution pipes. Fig. 86 shows a hydraulic screw joint, as used for coupling up two lengths of 1½-inch bore hydraulic piping. The end of one pipe is swelled up and screwed. The end of the other is formed with a collar. A gun-metal hexagon nut or coupling pulls the two ends together against a gasket or gutta-percha washer, bedding on, which makes the joint tight.

For joining up two lengths of a cast-iron transmission main, flanges with circular registers are cast on the ends of the pipe. On the flanges being drawn together, the protecting register beds on the gutta-percha ring, making the joint watertight.

Draw to a scale of full size—

A complete sectional elevation.
A complete side elevation.
An end elevation, and a plan.

Examples—

1. If the diameter of a pipe is very large compared with the thickness, as in the case of a boiler shell, we have the simple formula—

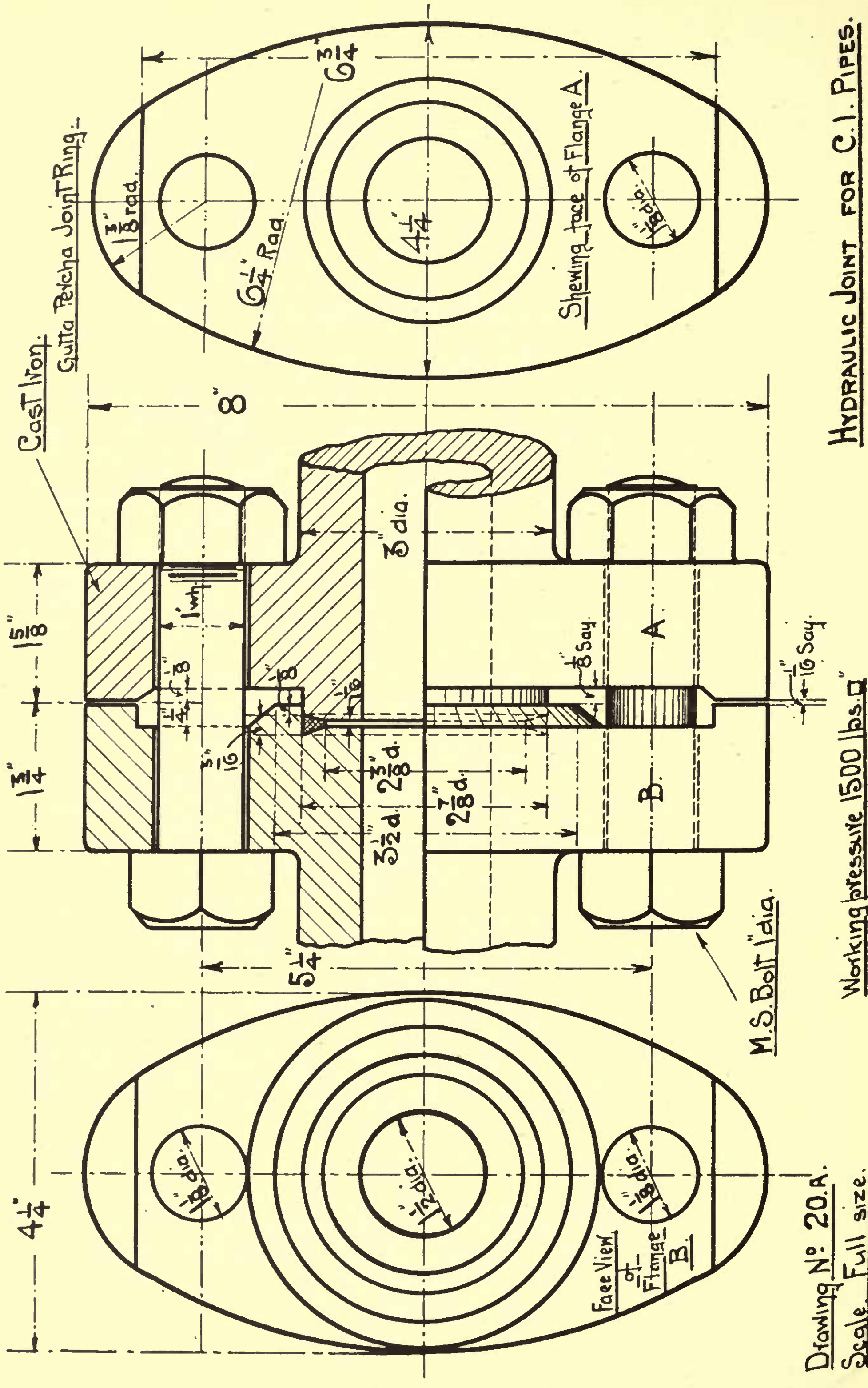
$$t=\frac{p \times d}{2 \times f} \text{ inches.}$$

t = thickness of walls.
p = working gauge pressure in lbs. per square inch.
d = internal diameter in inches.
f = working stress on the material in lbs. per square inch of cross section.

If, however, the diameter of the pipe be not large compared with the thickness, as in the case of hydraulic pipes, the production of a formula is more difficult, but we have—

$$f=p\frac{r_o^2+r_i^2}{r_o^2-r_i^2}.$$

p = working pressure in lbs. per square inch by gauge.
r_o = outside, and r_i = inside radius of pipe.
f = working stress in lbs. per square inch produced in the pipe material by the pressure p.
$r_o - r_i$ = the thickness of the pipe.


HYDRAULIC JOINT FOR C.I. PIPES.
Drawing No 20.A.
Scale Full size.
Working pressure 1500 lbs.□
M.S. Bolt 1" dia.
Cast Iron.
Gutta Percha Joint Ring.
Shewing face of Flange A.
Face View of Flange B.
A.
B.
6 3/4"
6 1/4" Rad.
1 3/8" rad.
4 1/4"
8"
3" dia.
1 5/8"
1 3/4"
5 1/4"
1/8" Say.
1/16" Say.
2 3/8" d.
2 7/8" d.
3 1/2" d.
1 1/2" dia.
1 1/8" dia.

A. In the case of the steel piping, fig. 86, show that the working stress in the material is 5835 lbs. per square inch.

B. In the case of the cast-iron piping, Drawing No. 20A, show that the working stress in the material is 2500 lbs. per square inch.

2. Suppose the pipe on which one flange is formed to be rigidly fixed, and the pipe on which the other flange is formed to make a right-angle bend. Show that the load tending to pull the joint apart

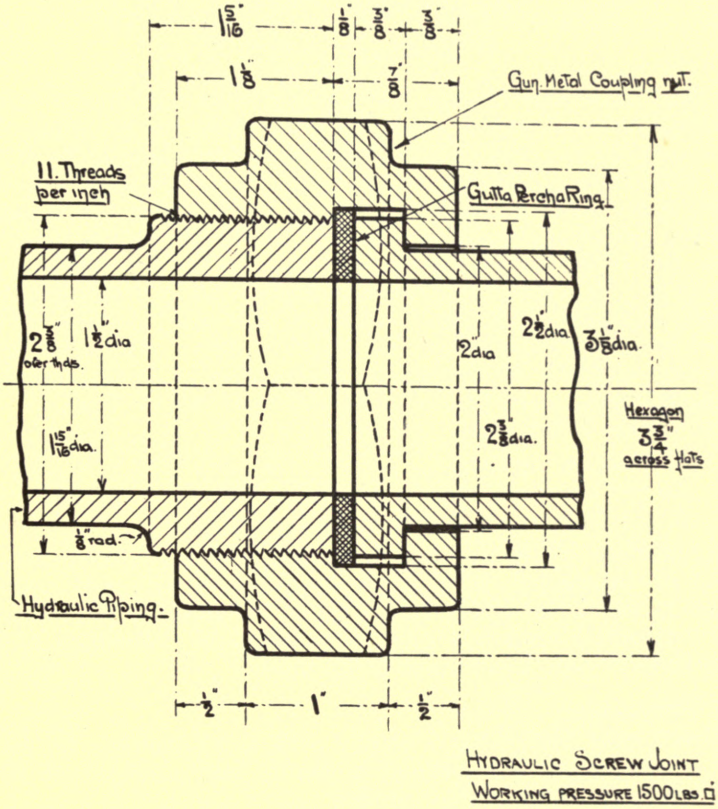


FIG. 86.

is 2640 lbs. Show that the stress measured on the body part of the bolts is 1680 lbs. per square inch. Show that the stress measured on the area of the bottom of the threads of the bolts is 2382 lbs. per square inch.

3. Make to a scale of full size a drawing of the screw joint, fig. 86, giving—

A sectional elevation as shown.
An end elevation.
An outside side elevation corresponding to this section.
A plan.

HYDRAULIC PISTON.

Drawing No. 21.

THE reduction in volume which takes place when pressure is applied to water is so small that it may be neglected; thus, 1500 lbs. per square inch reduces the volume by 1 in 200. Also the applied pressure is transmitted through the water without loss. Energy can therefore be transmitted with economy by allowing water under pressure to operate a movable piston in a cylinder.

The piston given consists of two cast-iron discs securely fixed on the mild-steel piston rod by means of the pinned nut. To prevent leakage past the piston, which it is important should not take place, and yet to allow the piston to slide freely, that is, without undue friction, two cup leather packing rings are clamped back to back between the cast-iron discs. The efficiency of the piston packing depends altogether on the quality of these leathers, which should be made from specially selected oak-tanned butts or hides.

Draw to a scale of full size—

The section indicated.
An end elevation looking in the direction of the arrow.
A plan looking on top of this end elevation.

The application of hydraulic transmission is most suitable to machines intermittent in their action, such as presses, punches, lifts, and cranes. The easy manner in which the energy can be taken in suitable pipes from point to point with very small losses is a great advantage, the difficulties to be overcome being those of pipe friction and leaky joints.

Examples—

1. The piston shown has a stroke of 4 feet 6 inches. By means of a pulley-block arrangement it lifts its load a height of 18 feet at the rate of $2\frac{1}{2}$ feet per second.

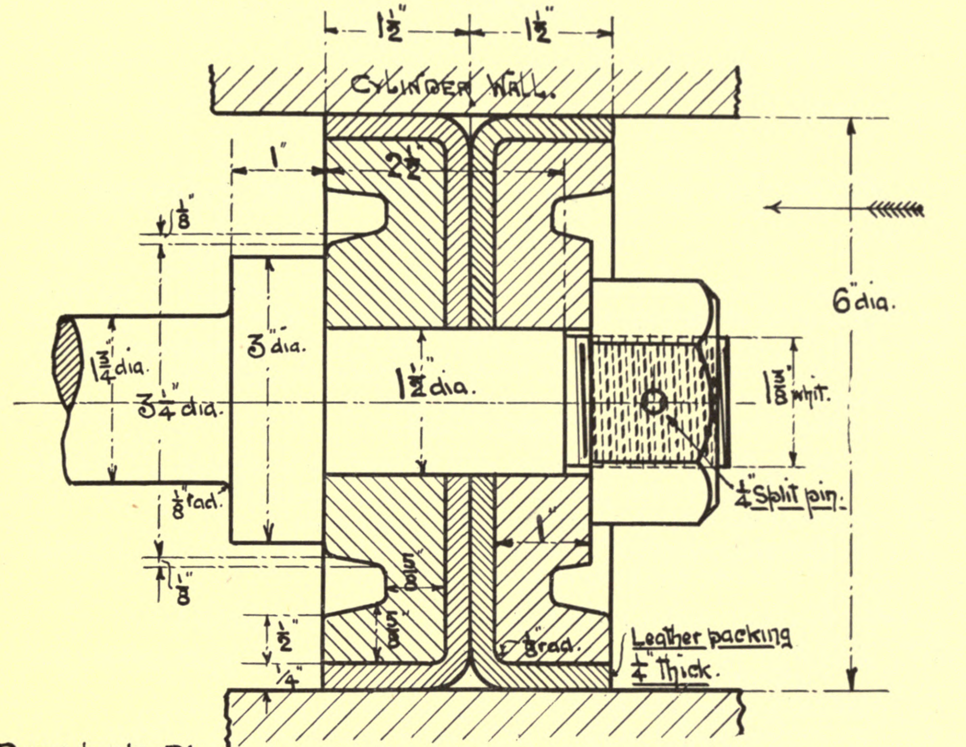
   (*a*) The supply pipe has an internal diameter of $1\frac{1}{4}$ inches; outside, $1\frac{3}{4}$ inches. Show that the velocity of the water through the supply pipe is 14·4 feet per second.

   (*b*) The pressure of the water-supply being 100 lbs. per square inch, the load lifted at the above rate 560 lbs., show that the mechanical efficiency of the crane is 79·2 per cent.

   (*c*) What volume and weight of water is used in one lifting stroke? *N.B.*—The water acting on the nut side of the piston. Also what volume and weight of water is wasted in bringing the piston back to its initial position?

   (*d*) Show that 24,358 foot-lbs. of water energy has to be used per lift, and that the commercial efficiency of the crane then becomes 41·4 per cent.

2. To resist corrosion in water containing acid, a lead bronze—77 parts copper, 8 tin, and 15 lead—is used. What is the value of raw metal in 1 lb. of the alloy? Take the value of the metals from the daily paper.



DRAWING No. 21.
SCALE FULL SIZE.

6" HYDRAULIC PISTON.

PISTON FOR 12 INCHES DIAMETER STEAM CYLINDER.

Drawing No. 21A.

EVERY heat-engine has a working substance, and heat-energy is converted into mechanical energy by the changes which take place in the volume or space occupied by this working substance. In a reciprocating steam engine we have the piston-cylinder arrangement, the piston changing its position in the cylinder giving the required volume changes.

The piston block, to be satisfactory, should—

1. Work freely in the cylinder, and, without undue friction on the sides of the cylinder, prevent the steam from leaking past it.
2. Be strong enough to carry the load coming on it.
3. Be rigidly attached to its piston rod, as the two details are subjected to severe reversals of heavy load.

Draw to a scale of half full size, showing all details assembled—

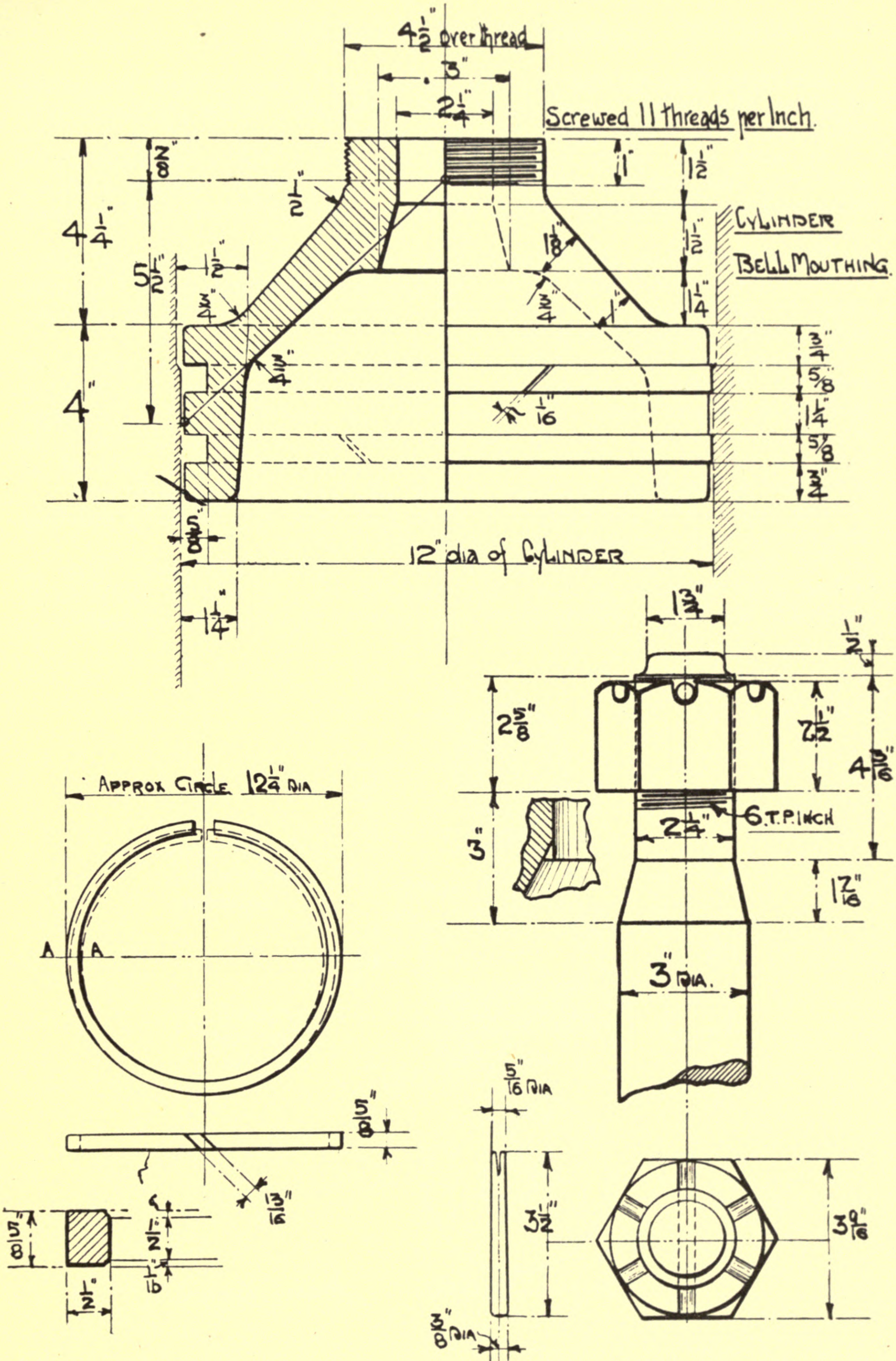
A side elevation, the half above the centre line to be in section, and that below the centre line in outside view.

An end elevation looking at the nut end of the rod.

An end elevation looking in at the other side of the piston block.

On the right-hand side of your drawing make a table giving Detail; No. off per set; Material; Pattern No.; Character of work to be done on detail for the particular piston and rod end shown, in which we have:—

The cast-iron block, which, to meet condition (1) above, is turned an easy fit to the bore of the cylinder, and then made steam-tight by fitting spring rings into grooves cut in the side of the block. A common and satisfactory form of ring is called the Ramsbottom ring, constructed somewhat as follows:—A short cast-iron ring is taken with machining allowances inside and out, for a 12-inch cylinder the outside diameter being 12·25 inches + machining allowance; inside diameter, 11·25 inches − machining allowance. A diagonal slot $\frac{13}{16}$ inch wide is now cut along the side of the ring, which is then cramped up in a jig and closed in until the faces of the slot come close up. The end of the ring standing out of the jig is then turned 12 inches and bored 11 inches diameter. Rings are then parted off wide enough to be a good fit sideways in the piston-block grooves. The rings produced fit closely a cylinder 12 inches bore, and as they tend to open out to a normal diameter of $12\frac{1}{4}$ inches, they exert a pressure on the walls of the cylinder, and will spring out to take up wear, thus maintaining the piston steam-tight during its motion.



DRAWING No. 21. A.
SCALE ½ FULL SIZE.

150. K.W. ENGINE
HIGH PRESS. PISTON.

Example.—The cylinder is 12 inches diameter; steam pressure on one side of piston, 175 lbs. per square inch; on the other side, 40 lbs. per square inch. What is the total load supported by the piston?

To carry such heavy loads with safety, piston blocks are made either conical or box section, well ribbed. The conical form enables a strong cover with small clearances to be used, and assists condensed steam to drain away.

The above load on the piston falls off at the end of each stroke, and is reversed in direction during the next stroke; hence the tendency of the piston block to work loose on the end of the rod, and the necessity of a secure method of fixing the two together.

The piston-block centre is bored to templet, so that end of rod will be an exact fit. The rod is made of mild steel turned to fit the recess, and fixed in position by the nut shown. To prevent the nut slacking back, a split taper pin is driven through the nut and the rod end. To allow the nut to be tightened up if any bedding down takes place, the nut is grooved or castellated so that it can be pinned at every sixth part of a complete turn.

The length of the rod itself, after turning, is finished off to size by grinding. This gives a truly cylindrical and a good skin surface.

Fig. 87.—To remove the piston from the cylinder, the joint must be broken, after removing the nut. Most probably the rod will be found to be jammed in the block. The piston wrench consists of a nut then screwed on to

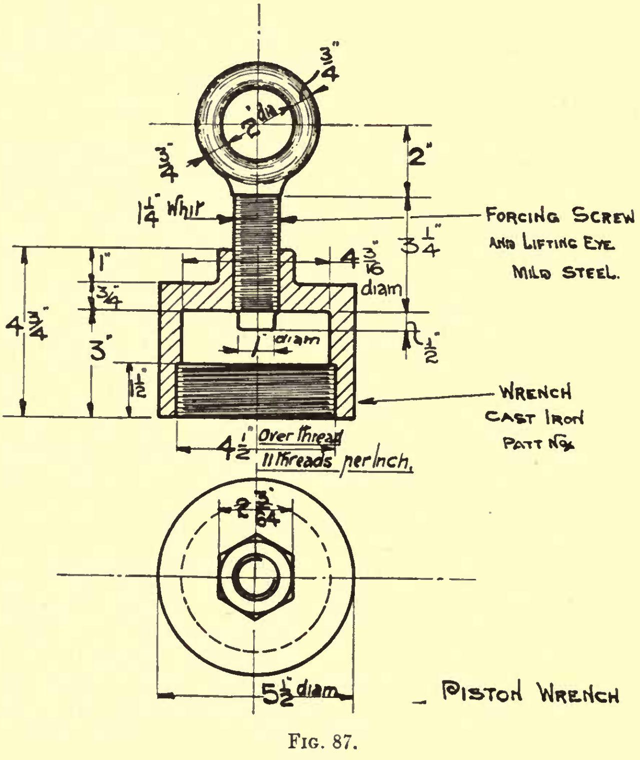


Fig. 87.

the back boss of the piston, and the forcing screw being turned forces the rod apart from the block. Afterwards the eye-bolt enables the piston to be lifted from the cylinder, which in this case is vertical.

Examples—

1. Estimate roughly the weight in lbs. of the piston block, given 1 cubic inch of cast-iron weighs 0·26 lb.
2. Explain the process of assembling or placing the piston block with its rings inside the cylinder.
3. Sketch and describe—
   (*a*) An alternative arrangement of piston ring or rings.
   (*b*) An alternative method of fixing the block to the rod.

GAS ENGINE PISTON.

Drawing No. 21B.

THE gas engine is a machine for converting natural energy into mechanical energy. The essential parts of such an engine are indicated by the line diagram fig. 88, and the engine works on a four-stroke cycle:—

1. Suction stroke. A mixure of air and gas in the proportion, say, 10 to 1 for town gas is drawn into the cylinder.
2. Compression stroke. This mixture is compressed up into the clearance space. At the end of the stroke it is fired; heat is liberated, while the gas remains practically at constant volume, with the result that the temperature and pressure of the mixture rise greatly.
3. Working stroke. The products of combustion at high pressure expand, forcing out the piston and giving up energy to the crank-shaft.
4. Exhaust stroke. During the next in-stroke the spent gases escape from the cylinder to the air.

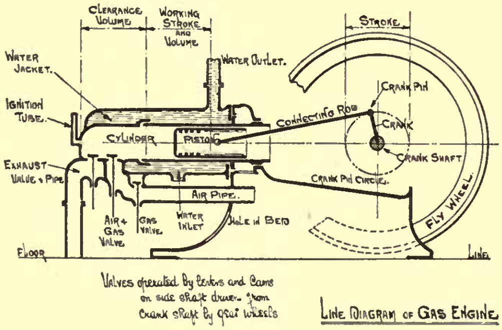
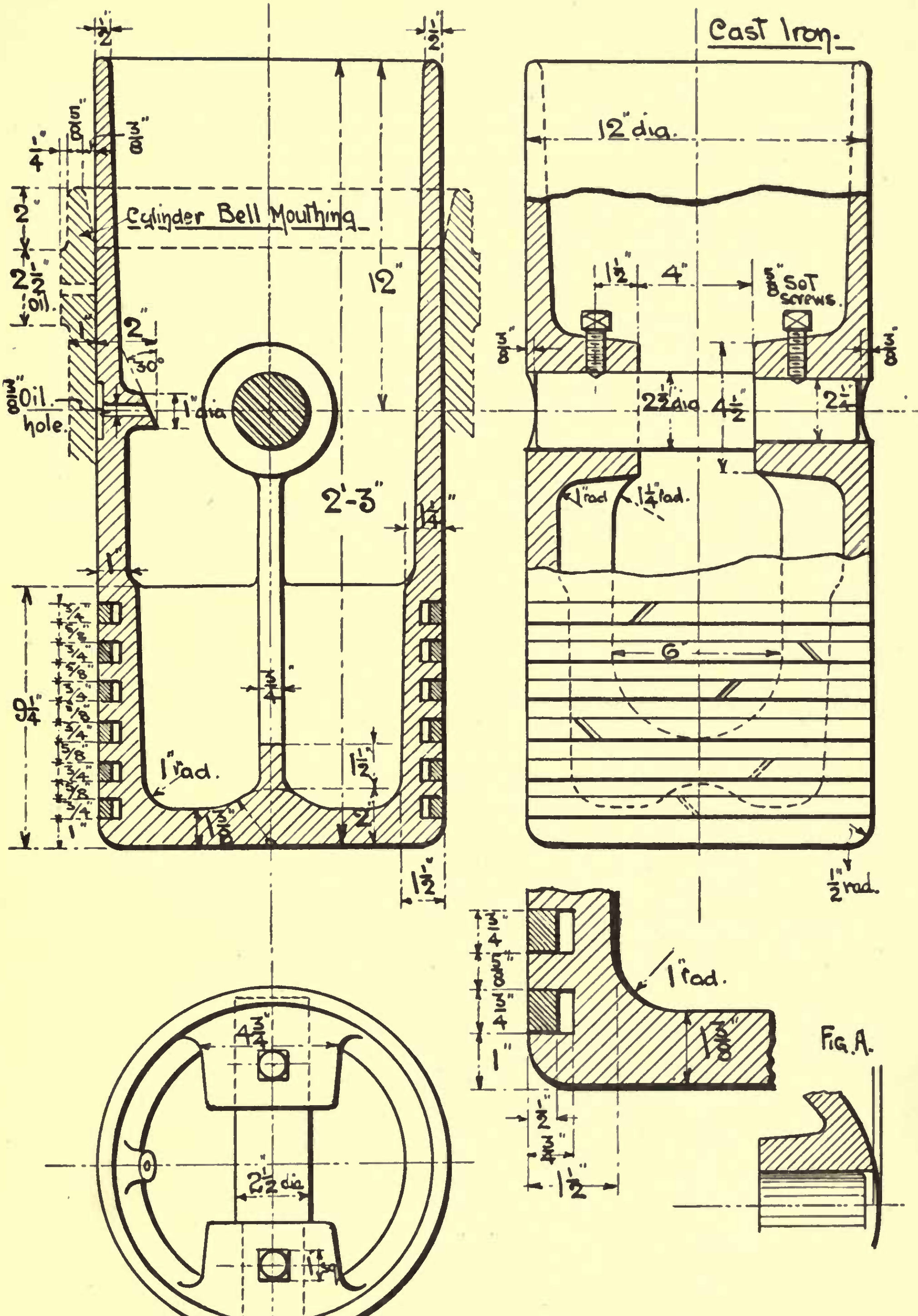


FIG. 88.

For economy in gas consumption the pressure at the end of the compression stroke is fairly high, say 75 lbs. per square inch. As this is produced by gradually compressing the mixture of gas and air, it is very important that the piston packing be effective against leakage.

When the gas is fired the pressure due to the heat liberated rises to, say, 250 lbs. per square inch. The gas at this pressure then expands, driving out the piston. Again, to get the maximum energy out of the gas, piston leakage must be reduced to a minimum.

Drawing No. 21B shows a piston used to satisfy these requirements.



Drawing No. 21. B.
Scale 3/8s Full size.

12" TRUNK PISTON.
GAS ENGINE.

The cast-iron trunk piston is turned an easy fit to the bore of the cylinder, and grooved for the six cast-iron Ramsbottom spring rings. The gudgeon pin on which the connecting-rod oscillates is fixed in the piston by the two steel screws; its length must be such that the flat ends do not project outside the barrel surface of the piston, and as shown in fig. A. The internal pip which drips the lubricant on to the end of the connecting-rod, which is scooped out to catch it, and so lubricate the gudgeon pin, must be shifted so that the lowest point of the pip comes on the centre line.

Draw to a scale of three-eighths full size—

A sectional elevation as shown.
A plan in outside view.
An end elevation looking inside the piston.

At the end of the compression stroke, before the mixture is fired, its temperature may be about 400° F. Immediately after firing, the heat liberated will raise this to about 3000° F. The use and necessity of the water-jacket are at once seen. To keep the piston cool enough to make lubrication possible, it is constructed of the trunk form, and single-acting; that is, the gas only acts on one side of it, heat radiation from the open side preventing it attaining an unworkable temperature. In large engines, made double-acting, the piston is of different design, but arrangements have to be made to circulate cooling water through it.

Examples—

1. A gas engine cylinder is 12 inches diameter; the piston has a stroke of 24 inches. What is the working volume in cubic feet?
2. What is the volume of air and gas at the end of the suction stroke, if the clearance volume is three-eighths of the working volume?
3. If the relation between pressure and volume during compression is at every point represented by the expression $p \times v^{1 \cdot 3} = \text{constant}$, the pressure at the end of the suction stroke being 14·7 lbs. per square inch, what is the pressure at the end of the compression stroke? Neglect the increase of pressure due to temperature rise produced by the heat received from the cylinder during the compression stroke.

STEAM TURBINE BLADES.

Drawing No. 21C.

In the reciprocating engine the change of volume is obtained by the piston cylinder mechanism. A steam turbine is a rotary engine, and the volume changes take place, first:—

Laval Type (fig. 89).—In a conical or diverging nozzle or nozzles fixed in the casing. In these the heat-energy is converted into kinetic energy, which has then to be transferred to the rotor of the engine, which consists of a wheel mounted on a shaft, carrying on its rim blades on which the steam jet acts, giving an impulse turbine. For efficient working—

1. The absolute velocity of the jet leaving the blades must be as small as possible.
2. The jet must enter the blades without shock—that is, the first part of the blades must be in the direction of the relative motion of the steam jet to the wheel.

Thus, in the drawing, section on AB—

v_1 = velocity of steam jet from nozzle.
w = velocity of wheel, centre of blade length.
r = direction of relative motion, jet to wheel, and inside edge of blade is tangent to this line.
a = velocity of steam jet leaving the wheel.

Draw to a scale of twice full size a portion, say one-quarter, of the wheel rim as given. For setting out the blade angle, take the mean speed of the wheel as 500 feet per second, and the steam-jet velocity as 2500 feet per second.

Examples—

1. The velocity of the mean circle for the blade length being 500 feet per second, express this in revolutions per minute and radians per second.
2. The weight of one blade being 95 grains, what pull in lbs. does it exert on the wheel rim due to centrifugal effect (1 lb. = 7000 grains)?

In the second, **Parsons,** type of turbine (fig. 90) the whole energy is not

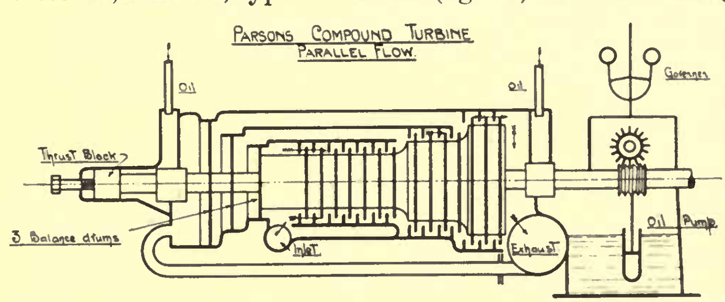
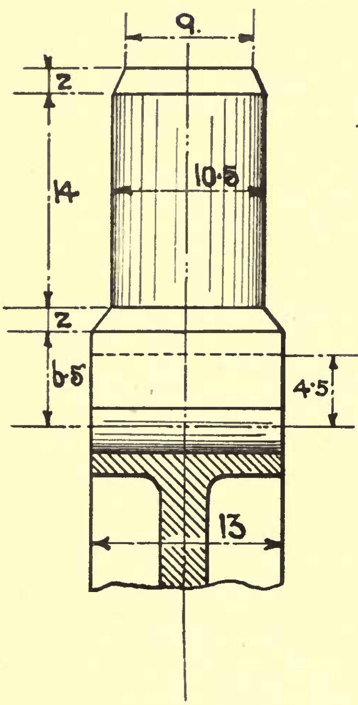
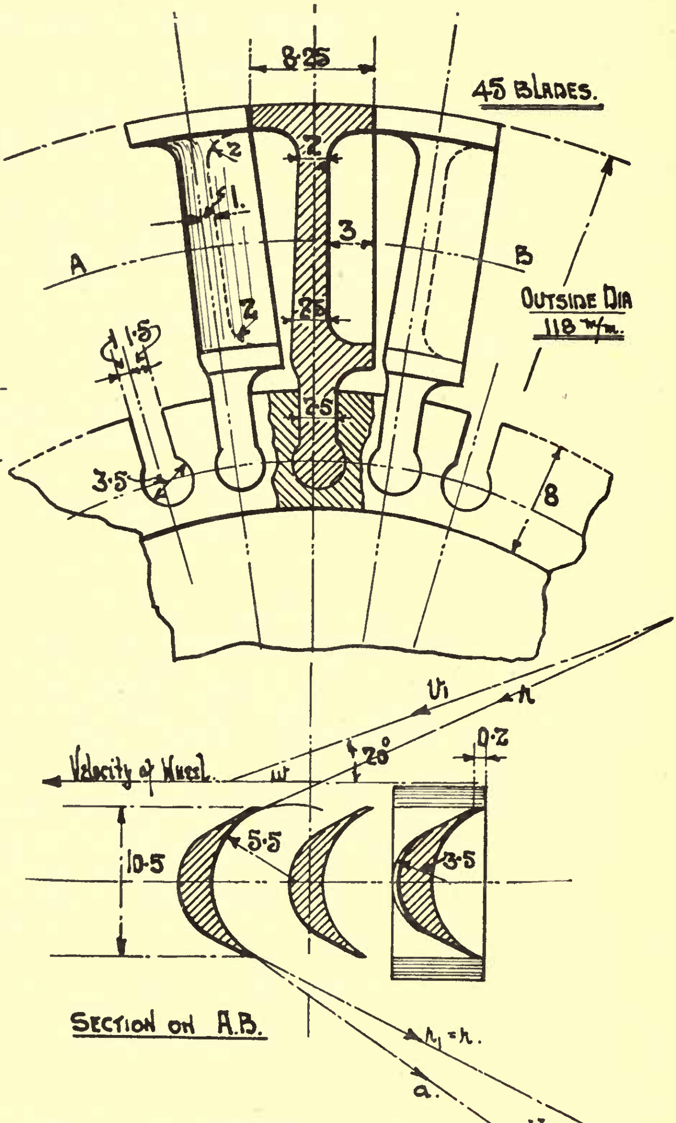


Fig. 90.





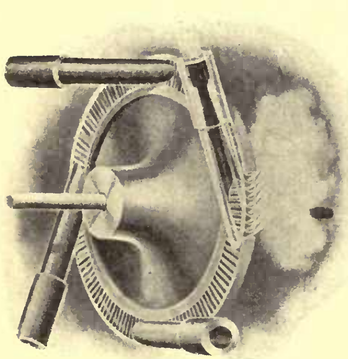


FIG. 89.

DRAWING No 21. C.
WHEEL BLADE. 5. H.P. LAVAL TURBINE.

Scale Twice Full Size.

converted into kinetic energy in one nozzle or set of nozzles, but the expansion is gradual in both the fixed and moving blades, and the kinetic energy is taken out of the steam in stages; hence a different type of blade is used. Rings of blades are fixed alternately on the casing and to the rotor. The steam expands in these rings of blades, completely filling them, and to prevent leakage endways minimum clearances become of great importance.

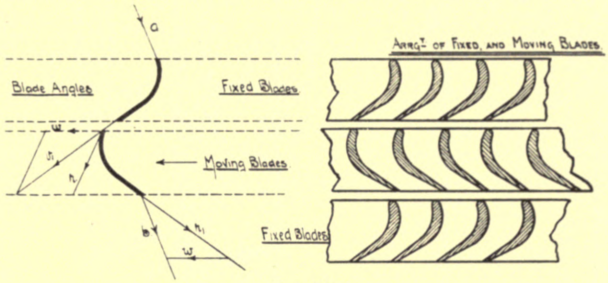


FIG. 91.

a = velocity of steam entering fixed guide vanes.
v_1 = steam velocity on leaving; is greater than a, due to expansion.
w = wheel velocity.
r = relative velocity of steam entering wheel or moving vanes.
r_1 = velocity of steam leaving wheel; greater than r, due to expansion
b = velocity of steam entering next set of guide vanes.

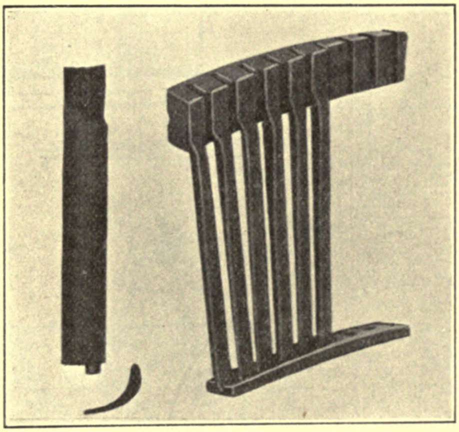
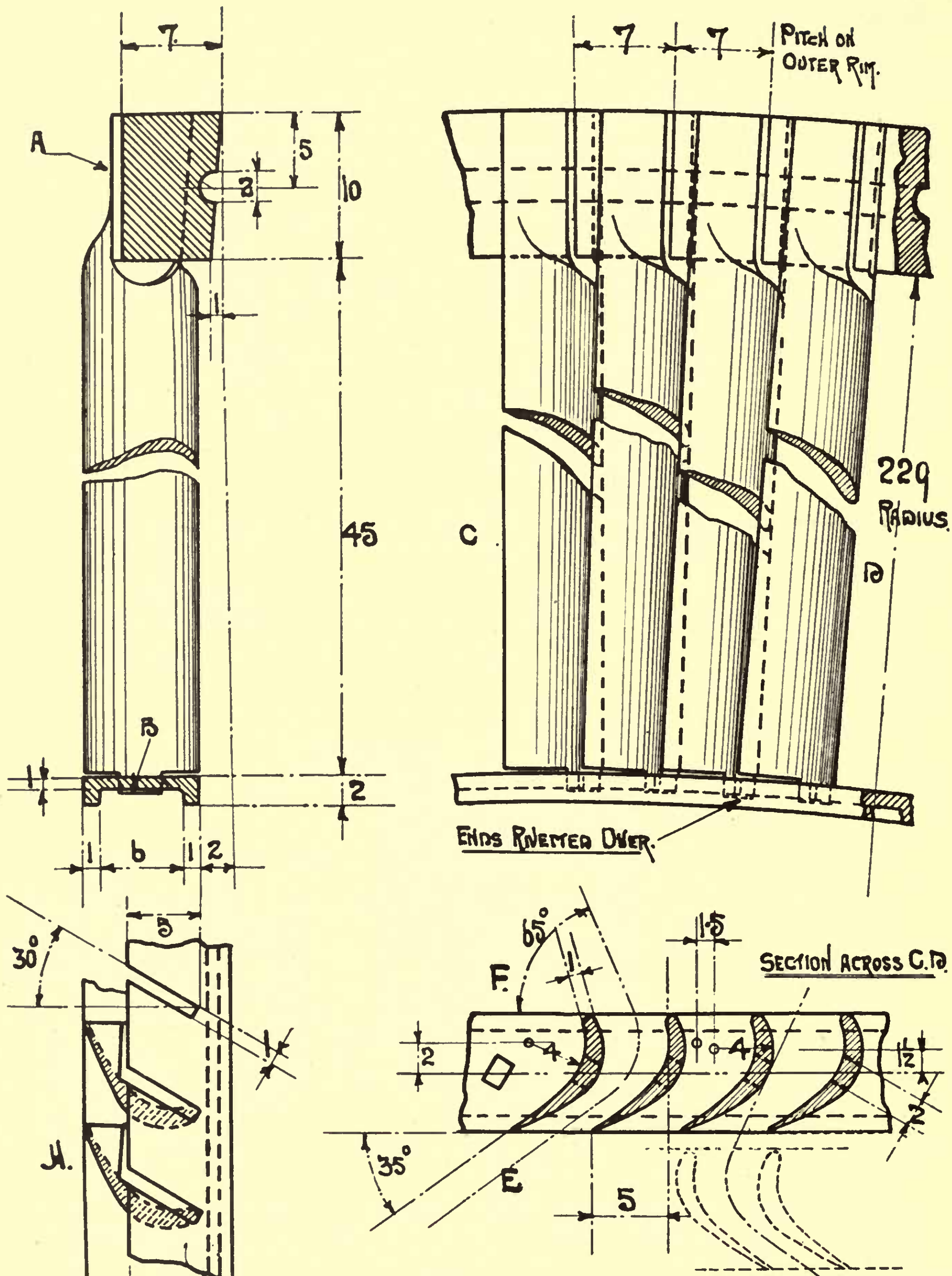


FIG. 92.—Turbine Blades.

Drawing No. 21D shows a portion of one ring of casing or guide blades from a 2000 K.W. Willans-Parsons turbine, the diameter of the rotor at the small end being 18 inches, the rotor making 1300 revolutions per minute. Steam enters from the side F. Expanding, gaining velocity and kinetic energy, leaving on the side E, it is deflected or guided into similar but reversed blades,



FIRST RING OF CASING BLADES.
2000 K.W. PARSON'S TYPE TURBINES

DRAWING No. 21.D.

as indicated, mounted on the drum-shaft or rotor, to which it gives up energy, and on leaving passes into another ring of casing blades, which turn it into another set of rotor or moving blades; and so on until it reaches the end of the first stage.

To accommodate the increasing volume of steam, the next stage drum and casing are made larger in diameter, and the process of the steam passing through fixed and moving blades repeated, until finally the steam exhausts into the condenser pipe.

Draw to a scale of twice full size a portion of one ring of the fixed blades as shown.

Example.—Verify that the weight of one blade is 5·08 grammes, the material being phosphor-bronze. Express this weight in grains.

Assume it is fixed on the rotor, and the outside top diameter to be 18 inches. What force is required to restrain the centrifugal effect at 1300 revs. per minute?

FLY-WHEEL.

A FLY-WHEEL is a store or reservoir of energy, taking up energy when the effort is greater than the load, giving out energy when the effort is less than the load.

At any given speed the energy in the wheel is given by—

$$\text{Kinetic energy} = \frac{Wv^2}{2g} \text{ foot-lbs.} \quad . \quad . \quad . \quad . \quad . \quad (1),$$

if W is the weight in lbs.

v, the velocity in feet per second at the effective radius of the wheel.

g, the gravitational constant, is 32·2 feet per second.

It is convenient to have modifications of this expression for the stored energy.

First, to express it in terms of the revolutions per minute, N.

We have $$v = 2\pi R \frac{N}{60} \text{ feet per second.}$$

$$KE = \frac{Wv^2}{2g} = \frac{W(2\pi R)^2}{2g \,.\, 60 \,.\, 60} \times N^2$$

$$= MN^2 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2),$$

where M has a particular value for any given wheel.

Second, to express it in terms of I, the moment of inertia, and ω, the angular velocity of the wheel, ω being in radians per second.

We have $$v = R\omega.$$

Hence, $$KE = \frac{Wv^2}{2g} = \frac{WR^2}{g} \cdot \frac{\omega^2}{2} = \tfrac{1}{2}I\omega^2. \quad . \quad . \quad . \quad . \quad . \quad (3),$$

where $I = \frac{WR^2}{g}$ and is called the moment of inertia of the wheel.

R is the radius of gyration of the wheel, that is, the effective radius of the wheel in feet.

For a rectangular section rim, inside radius R_i, outside radius R_o, and neglecting the arms and boss,

$$R = \sqrt{\frac{R_o^2 + R_i^2}{2}}.$$

For any other section of rim, or to take the arms and boss into account. R can be obtained by calculating the moment of inertia of the whole wheel about the shaft axis.

Limiting Rim Velocity.—The energy stored in a wheel depends upon its weight, that is, the dimensions of the wheel, and the square of practically the rim velocity. The dimensions are often fixed by general appearances of the machine. The rim velocity is limited by the strength of the material used in the construction of the wheel.

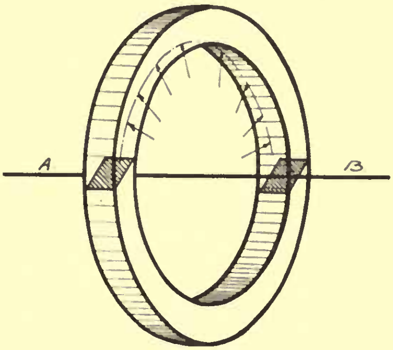


FIG. 93.

Consider the rotation of a hoop (fig. 93): effective radius, 1 foot; cross section, 1 square inch.

To restrain the motion of each element of the ring in its circular path, a force radial towards the centre must be exerted on it, and

$$\text{On each element this force} = \frac{Wv^2}{gr}.$$

The resultant or total effect of all these elementary forces is to tend to rupture the ring across a diametrical section, as AB.

$$\text{This resultant} = \frac{Wv^2}{gr} \times 2r = \text{centrifugal force per foot of rim} \times \text{projected area},$$

and is resisted by two cross-sectional areas each 1 square inch.

Taking f as the safe working stress on the cross section in lbs. per square inch,

$$\frac{Wv^2}{gr} \times 2r = 2f \times 1 \times 1.$$

Taking the material as cast-iron, W, the weight of 1 foot length of rim, section 1 square inch = $12 \times {\cdot}26$ lbs.; and f, the safe working stress in lbs. per square inch, being taken as $1\frac{1}{2}$ tons, we have for the limiting rim velocity

$$\frac{12 \times {\cdot}26 \times v^2}{32{\cdot}2} = 1{\cdot}5 \times 2240.$$

$$v^2 = \frac{1{\cdot}5 \times 2240 \times 32{\cdot}2}{12 \times {\cdot}26}.$$

$$v = 186 \text{ feet per second.}$$

If a fly-wheel is subjected to rapid variations of speed, important stresses due to inertia may be set up. Hence the rim speed of cast-iron fly-wheels is, on the average, not greater than 7000 feet per minute for solid wheels, and 5000 feet per minute for built-up wheels.

The use or function of the fly-wheel depends upon the character of the work to which it is applied, thus:—

With a reciprocating steam engine its object is to steady the engine speed.

With a press or punching machine, its object is to store up energy to produce a heavy blow for the bending or shearing of material.

Any change in the speed of a fly-wheel must be accompanied by a change of stored energy.

FLY-WHEEL FOR POWER PUNCH PRESS.

Drawing No. 22.

THE wheel is keyed to and rotates the sleeve of a clutch, which, when thrown into gear by a foot-lever, operates the ram carrying the punch; otherwise the wheel and clutch revolve freely on a stud pin. The press is used for light punching and blanking, and is driven by a 3 inches wide single leather belt running on the rim of this fly-wheel.

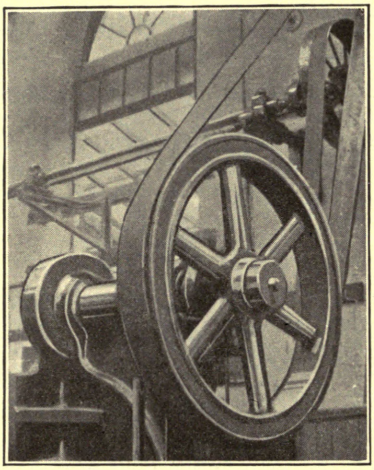


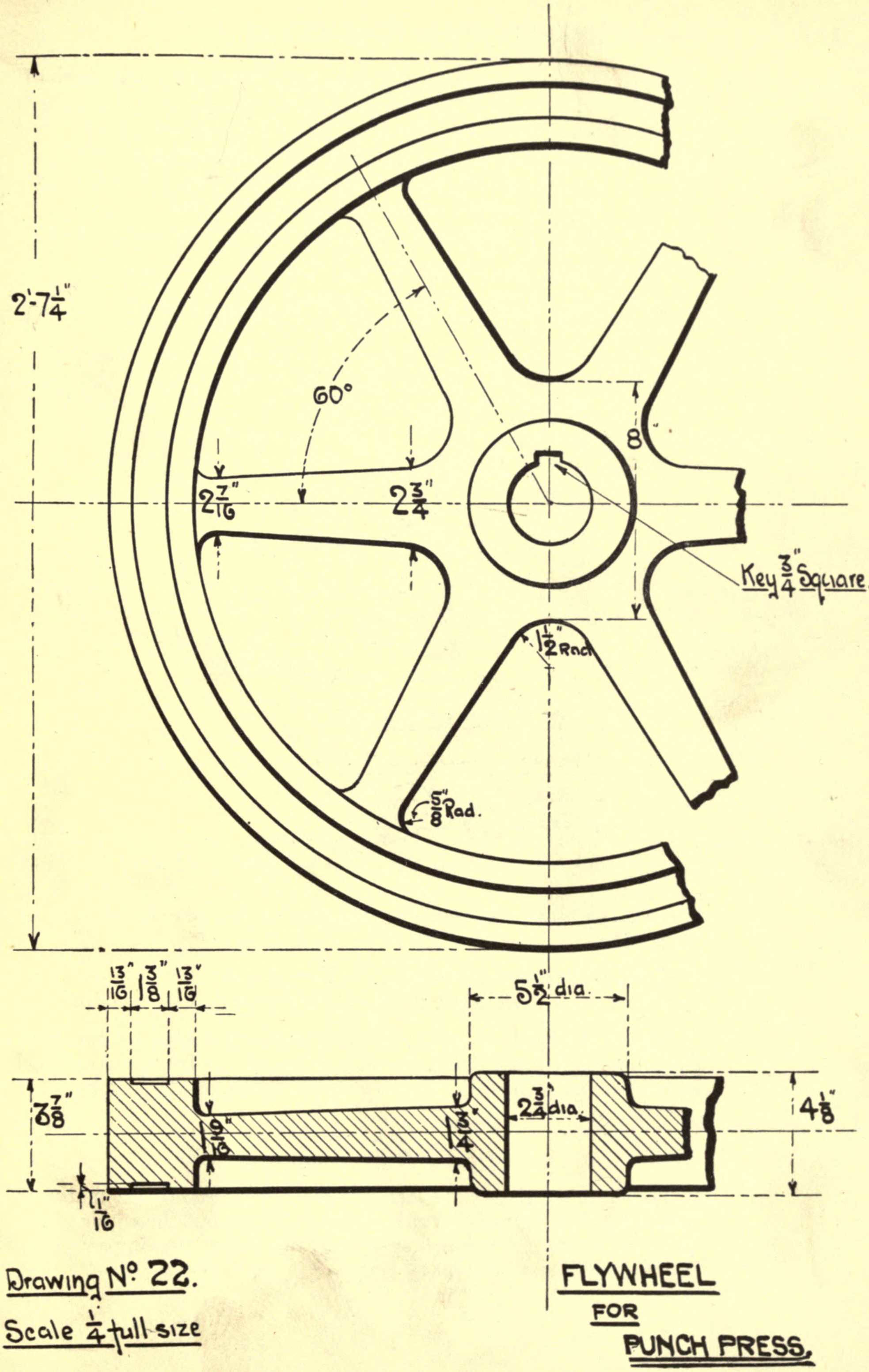
FIG. 94.—Power Press Fly-wheel.

Draw to a scale of quarter full size a front elevation, a side elevation, and a sectional plan as indicated.

The normal speed of the fly-wheel, running free, is 80 revs. per minute. When the clutch is thrown in, the wheel just pulls up dead when blanking and punching a plate with the dimensions and form shown in fig. 95 out of hard-drawn sheet brass $\frac{1}{16}$ inch thick.

Examples—

1. Show that the weight of the fly-wheel rim is 270 lbs.
2. Show that the radius of gyration of the rim is 14·25 inches, and that the kinetic energy of the rim at 80 revs. per minute is 415 foot-lbs.
3. Set out the detail fig. 95, and verify that the total outline of the area measures 30·5 inches.


2'-7¼"
60°
8"
2 7/16"
2¾"
Key ¾" Square.
1½" Rad.
⅝" Rad.
13/16" 1⅜" 13/16"
5½" dia.
3⅞"
9/16"
1¾"
2¾" dia.
4⅛"
1/16"
Drawing Nº 22.
Scale ¼ full size
FLYWHEEL
FOR
PUNCH PRESS.

4. To estimate the resistance offered by the hard brass per square inch of sheared area.

We have—

Periphery of area blanked out, 16·75 inches.
Periphery of punched area, 10·75 inches.
Circumference of punched holes, 3 inches.
Total periphery of the detail, 30·5 inches.

As this is taken out of plate $\frac{1}{16}$ inch thick,

$$\text{Area sheared} = 30{\cdot}5 \times \tfrac{1}{16} = 1{\cdot}91 \text{ square inches.}$$

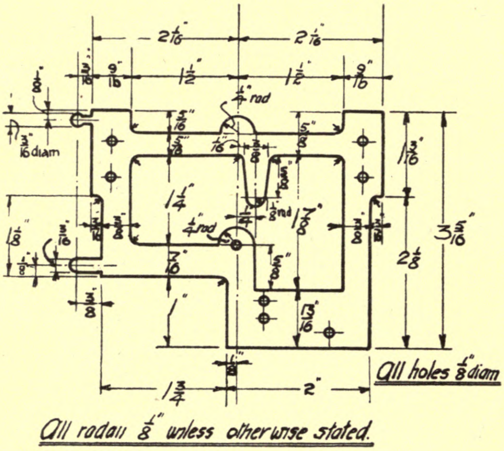


Fig. 95.

Let F = the mean resistance to shearing in lbs. per square inch of sheared area.

$$\text{Total resistance to shearing} \quad = F \times 1{\cdot}91 \text{ lbs.}$$
$$\text{Work done in obtaining plate} = F \times 1{\cdot}91 \times \tfrac{1}{16} \times \tfrac{1}{12} \text{ foot-lbs.} \quad (1)$$

Neglecting friction in the machine and any action of the belt, the work done must equal the energy given up by the fly-wheel as it just comes to rest. From example 2 this is 415 foot-lbs.

$$\therefore \qquad F \times 1{\cdot}91 \times \tfrac{1}{16} \times \tfrac{1}{12} = 415.$$
$$F = 42{,}000 \text{ lbs. per square inch.}$$

This number gives the average resistance offered by the material, assuming that a steady force is applied throughout the whole of the $\frac{1}{16}$-inch motion. Strictly speaking, we have an impact of a moving against a stationary body.

Another method of obtaining the average force exerted by the punch during the time of the blow is by considering the momentum transferred, thus:—

The fly-wheel is pulled up in a distance of 6 inches along its outer rim, from the time the punch strikes the plate until it stops. The time of stopping, assuming it slows down uniformly,

$$=\text{twice the time of one ordinary rev.} \times \frac{6}{\text{circumference of rim}} = 2 \times \frac{60}{80} \times \frac{6}{98} \text{ sec.}$$

But we have

$$\text{Force} = \text{rate of change of momentum,}$$
$$\text{Force} \times \text{time} = \text{mass} \times \text{change of velocity,}$$

from which we obtain the average force exerted on the material during the time it is shearing through the $\frac{1}{16}$ inch of material. Thus

$$\text{Force} \times \text{time} = \frac{\text{Weight in lbs.}}{32{\cdot}2} \times (\text{velocity of radius of gyration} - 0).$$

$$\text{Force} \times \frac{60}{80} \times \frac{6}{98} \times 2 = \frac{270}{32{\cdot}2} \times \frac{2\,.\,\pi\,.\,14{\cdot}25\,.\,80}{12\,.\,60}.$$

$$\text{Force} = 900 \text{ lbs.}$$

That is, during pulling up the rim exerts an average force of 900 lbs.; and this is exerted for a distance of 6 inches. Since the mechanism of the press reduces this distance to $\frac{1}{16}$ inch, that is, in the ratio 1 to 96, the force is magnified in the inverse proportion.

$\therefore$ Average force exerted by punch during blow $= 900 \times 96 = 86{,}400$ lbs.

Since the area sheared through is 1·91 square inches, the average resistance to shear of hard-drawn sheet brass is

45,000 lbs. per square inch.

The first method gave a less value, due to the fact that the kinetic energy taken is that due to the rim only, and neglects the effect of the arms and boss and belt action.

GAS ENGINE FLY-WHEEL.

Drawing No. 22A.

SHOWS part of the single fly-wheel used for a 10 brake horse-power gas engine.

Draw to scale of one-eighth full size—

A front elevation of the complete wheel, all six arms being drawn in correctly.

An end elevation, the half above the centre line being in section, the half below the centre line in outside view, all hidden parts being shown dotted. Fully dimension in millimetres.

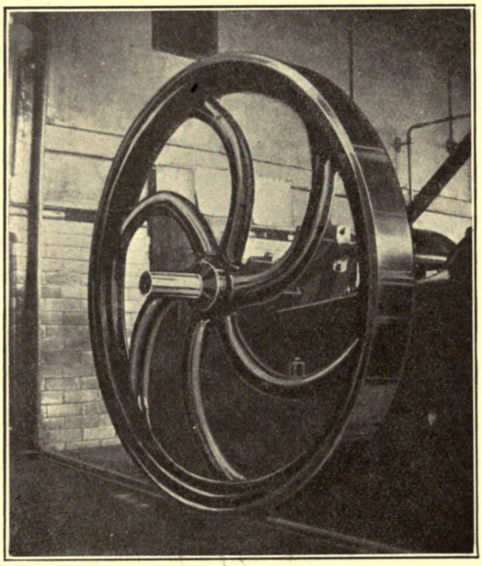
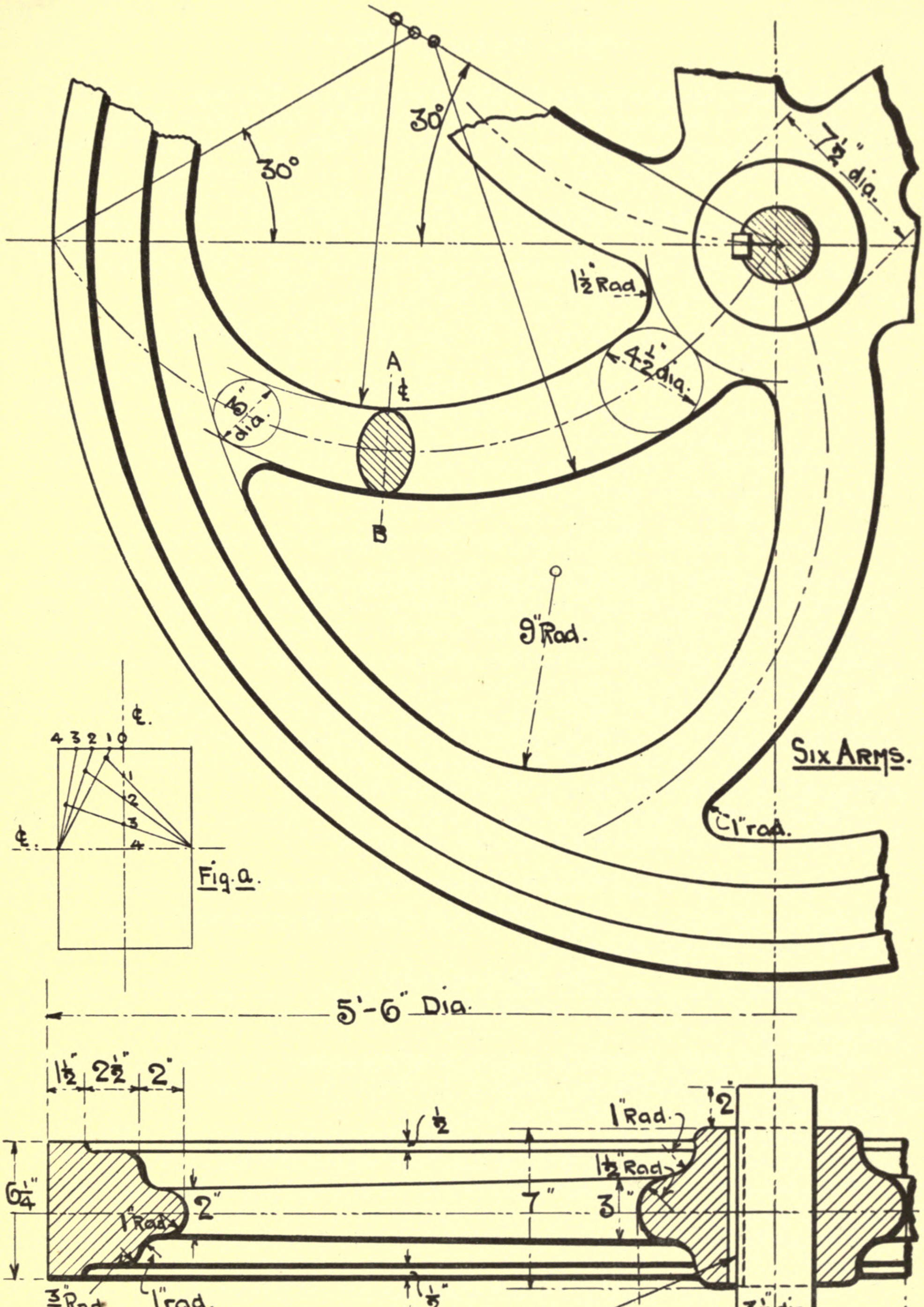


FIG. 96.—Gas Engine Fly-wheel.

The cross section of the arm at any point is elliptic, as shown at AB, the width of the arm being $1\frac{1}{2}$ times the thickness.

The method of setting out the elliptic section is shown in fig. *a*, where each semi-axis has been divided into four equal parts.

For greater accuracy, a greater number of points should be taken along each line. (Each of the lines at right angles must be divided into the same number of equal parts.)



Drawing No. 22A.

Scale $1\frac{1}{2}$ ins. = One foot.

10. B.H.P. GAS ENGINE FLY WHEEL.

Example.—Set out the cross section of the arm at the root, to a scale of full size. The two axes will be $4\frac{1}{2}$ inches and 3 inches long respectively. Draw the rectangle and proceed as indicated. Then calculate the sectional area, noting that—

$$\text{Area of ellipse} = \frac{\pi}{4}\{\text{long axis} \times \text{short axis}\}.$$

Use of the Fly-wheel.—Small gas engines work on a four-stroke cycle. For an engine using town gas, one cycle will be—

First Stroke.—A mixture of air and gas in the proportion 10 to 1 is drawn into the cylinder.

Second Stroke.—The mixture is compressed. At the end of this stroke the mixture is fired, burns with explosive violence, with the rapid liberation of heat.

Third Stroke.—The gases of combustion at high temperature and pressure act on the piston, doing work which is transmitted to the crank-shaft.

Fourth Stroke.—The burnt gases are exhausted into the atmosphere.

The fifth stroke is a repetition of the first, and the cycle is again repeated. There is at the best only one working stroke in every four—that is, one impulse for every two revolutions of the crank-shaft. During this working stroke, enough heat-energy has to be transformed into mechanical energy to maintain the crank-shaft energy for the time of two revolutions.

Of this mechanical energy, one-fourth is given out, *i.e.* taken from the crank-shaft during the working stroke; the remaining three-fourths is taken up and stored by the fly-wheel, to be given out during the next three strokes, during which there is no driving effort on the crank-pin.

This storing and restoring of energy by the fly-wheel can only take place by the speed of the wheel changing, and, as before,

$$\text{Energy in wheel} = M \times \text{revolutions per minute}^2.$$

The amount of variation which can be permitted depends altogether upon the class of work the engine is doing.

For ordinary purposes, $\dfrac{\text{total speed variation}}{\text{mean speed}}$ in one and the same cycle does not exceed $\frac{1}{30}$.

For special purposes, such as driving continuous-current dynamos for lighting purposes, this should not exceed $\frac{1}{50}$, while for driving alternators in parallel it should be brought down to $\frac{1}{150}$.

Example.—Ten B.H.P. gas engine at 180 revolutions per minute. Weight of fly-wheel rim = 1340 lbs.; boss = 110 lbs.; and arms = 360 lbs.

For steadying purposes take the wheel as a weight of 1810 lbs., with a radius of gyration 2·42 feet.

The engine works at the steady rate of 10 B.H.P., making 360 strokes per minute.

The energy taken from the crank-shaft during one stroke is

$$\frac{10 \times 33{,}000}{360} = 920 \text{ foot-lbs.}$$

The total energy developed during the working stroke is $920 \times 4 = 3680$ foot-lbs., and of this $920 \times 3 = 2760$ foot-lbs. is taken up by the fly-wheel, and its speed rises.

Take a minimum speed of 180 R.P.M. The energy stored in the wheel is $M \times N^2$ or $1{\cdot}8 \times 180 \times 180 = 58{,}320$ foot-lbs.

At the end of the working stroke this has increased to $(58{,}320 + 2760) = 61{,}080$ foot-lbs., and the revolutions per minute corresponding to this are given by

$$KE = MN^2; \text{ or}$$
$$61{,}080 = 1{\cdot}8 \times N^2, \text{ that is, 184 revolutions per minute.}$$

$$\text{Therefore} \qquad \frac{\text{total speed variation}}{\text{mean speed}} = \frac{184 - 180}{182} = \frac{1}{45{\cdot}5}.$$

Note.—$KE = \dfrac{W.v^2}{2g}$. $v = \dfrac{2.\pi.R.N}{60}$. N = revolutions per minute.

$$\therefore \qquad KE = \frac{W.2^2.\pi^2.R^2}{2.g.60^2}.N^2 = M.N^2.$$

R is the effective radius of the wheel, and in this example, taking rim, arms, and boss into account, $R = 2{\cdot}42$ feet, so that M becomes $1{\cdot}8$, the units being such that, with N in revolutions per minute, the energy is expressed in foot-lbs.

Examples—

1. When the wheel is making 180 revolutions per minute, what is the rim speed of the wheel expressed in feet per second?
2. Check the weights given for the rim, arms, and boss, and show that they are approximately correct.

$$\text{Note the ratio, } \frac{\text{weight of whole wheel}}{\text{weight of rim}} = 1{\cdot}35.$$

3. Explain the importance of the wheel bore being a good tight fit on the shaft, and the key well fitted.

STEAM ENGINE FLY-WHEEL.

Drawing No. 22B.

SHOWS one quarter of a built-up fly-wheel as used on a 2000 H.P. steam engine, driving direct an electrical machine generating alternating current, and the magnet wheel of which is bolted up direct to this wheel.

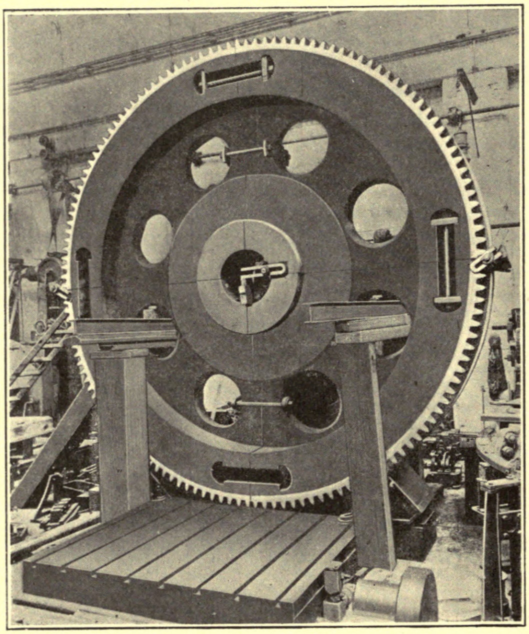


FIG. 97.—Steam Engine Fly-wheel.

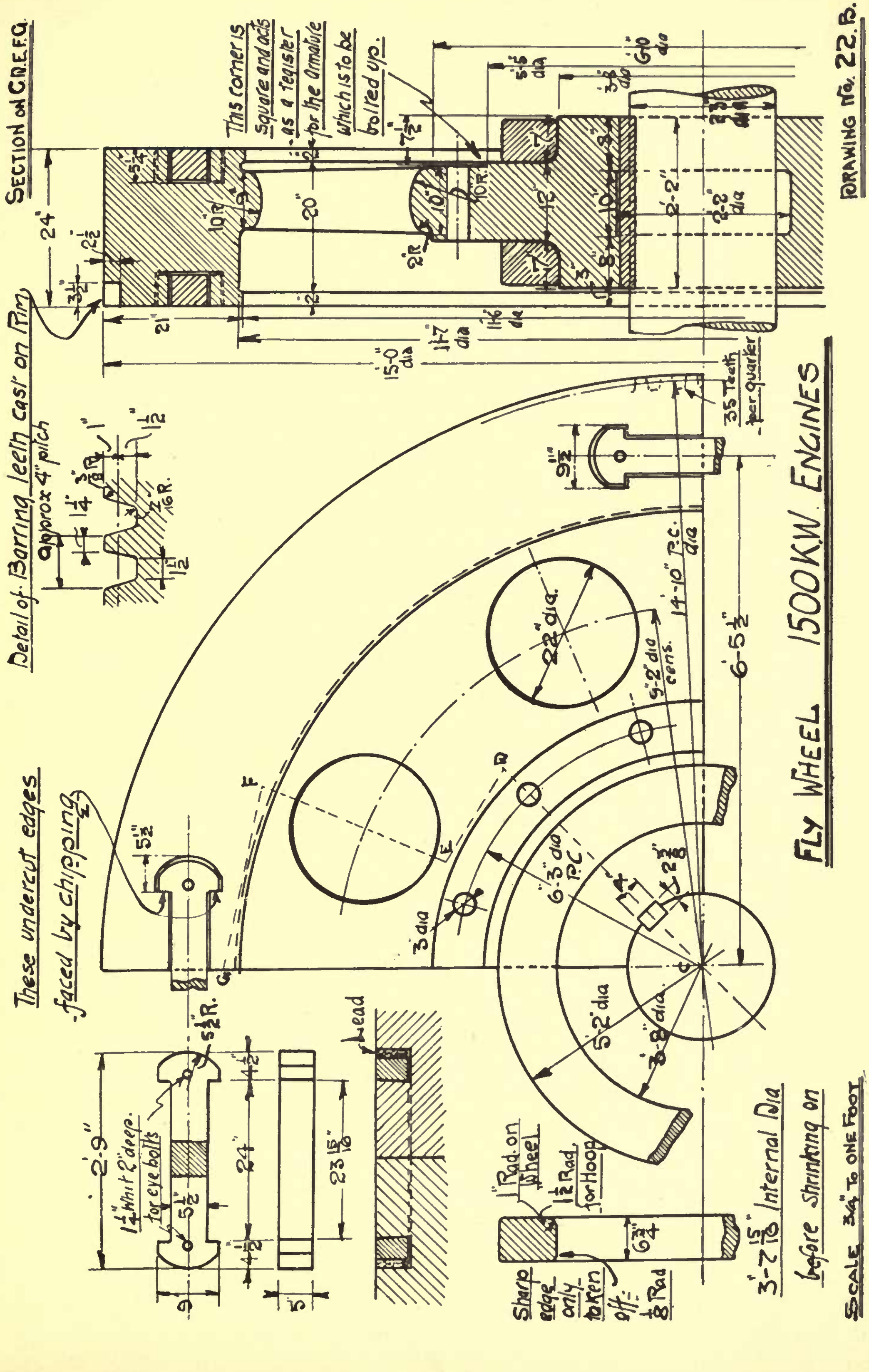
Draw to a scale of one-sixteenth full size—

A front elevation of the complete wheel. It will be sufficient to show the barring teeth for a short length only along the circumference, and indicate the remainder by a dotted circle.

A side elevation, showing the half below the centre line in outside elevation, and the half above in section along the line CDEFGH, just as indicated.

The parts of the wheel are held together, and on the shaft, by the two shrinkage hoops and the eight tee or dowel plates.

The hoops are turned all over, and $\frac{1}{16}$ inch is allowed on the internal diameter for shrinkage. To make certain of a good grip on the wheel boss,


SECTION ON C.D.E.F.G.
Detail of Barring teeth cast on Rim
approx 4" pitch
This corner is square and acts as a register for the armature which is to be bolted up.
35 Teeth per quarter
These undercut edges faced by chipping
1 1/4" Whit 2" deep. for eye bolts
Lead
1" Rad. on Wheel
1 1/2 Rad for Hoop
Sharp edge only taken off: 1/8 Rad
3'-7 15/16" Internal Dia before Shrinking on
FLY WHEEL 1500 K.W. ENGINES
DRAWING No. 22.B.
SCALE 3/4" TO ONE FOOT

the fillet in the corner of the wheel is taken out to a less radius than that to which the corner of the hoop is rounded off.

The dowel plates are machined on the flat sides and between the heads, the projections of which are tapered back, so that, when heated and dropped into their sockets, they on cooling become dovetailed in, after which the clearance spaces round the heads are run in with lead.

The allowance on the length for shrinkage is ·05 inch, and they must be heated sufficiently to allow the narrow dimension between the tee-heads to pass over the front dimension of the wheel socket.

Fig. 97 shows the complete wheel during the process of machining.

Function of the Fly-wheel in the case of a Steam Engine.—The speed of the engine measured in revolutions per minute may be quite constant, yet during the time of one revolution the speed may vary greatly.

The amount of variation which can be allowed is fixed by the quality and character of the work which the machinery driven by the engine has to do.

The turning effort on the crank-pin during the time of one revolution varies. With a constant load, when the effort is greater than the load the speed rises, and the speed falls when the effort is less than the load. The variations in turning effort are due to—

- The varying steam pressure on the piston.
- The changing kinetic energy in the parts moving backwards and forwards.
- The varying inclination of the connecting-rod.
- In a vertical engine, the rise and fall of the moving parts.

The variation due to each of these can be obtained separately and added together to give the total variation.

For an engine at given speed, the amount by which these changes will affect the speed depends upon the energy stored in the wheel, that is, the weight and diameter of the wheel.

The diameter of the wheel is usually fixed by general appearances, and for safety the rim speed should not exceed a value depending on the material.

For small solid wheels the usual speed is up to 7000 feet per minute.

For built-up wheels the usual speed is up to 5000 feet per minute.

Small wheels are sounder and more free from internal casting strains, and can therefore run faster.

Examples—

1. What is the periphery or rim speed of the wheel, Drawing No. 22B, expressed in feet per second, at 150 revolutions per minute?
2. The wheel rim, disc, and hub are of cast-iron, and the tees and hoops are of mild steel. Verify that the approximate weights are: rim, 29·7 tons; disc, 11·7 tons; hub, 3·25 tons; hoops, 2·5 tons; tees, ·525 ton; total, 47·675 tons.
3. The stored energy in a fly-wheel being 4 foot-tons per electrical horse-power, how many seconds' work of the engine does this correspond to?
4. The fly-wheel only of a steam engine giving 800 kilowatts at 175 revolutions per minute, and used for C.C. lighting and driving of workshops, stores 4,500,000 foot-lbs. of energy. Express this as so many seconds' work of the engine.

ALTERNATOR MAGNET WHEEL AND SHAFT.

Drawing No. 23.

THE cast-steel yoke casting is keyed to, and rotates with, the shaft, which is turned at a speed of 750 revolutions per minute by a raw hide pinion keyed on one end. The outline of the casting is an octagon or eight-sided figure, $11\frac{1}{4}$ inches across the faces, easily drawn in by using an auxiliary circle and the 45° set square. Attached to the periphery are eight magnet poles built up of laminated iron, steel castings, and copper insulated winding. For convenience in building up and repair in case of breakdown, the poles are constructed so that each pole can be removed from the machine complete in itself. It is necessary to securely fix each pole to the rim of the wheel, so that there is no danger of any part coming loose.

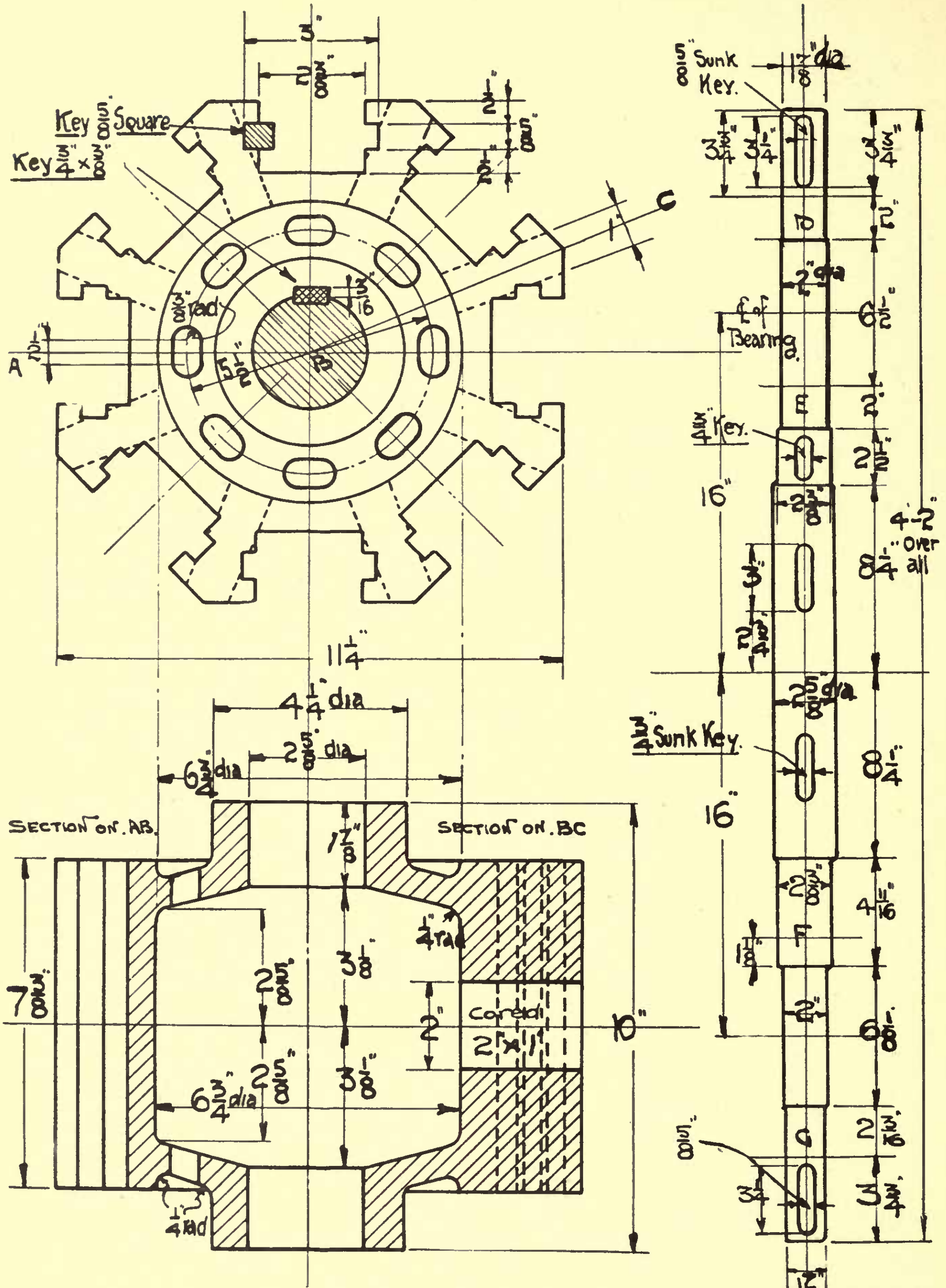
Draw to a scale of three-quarters full size two views of the wheel detail, one view being an outside front elevation, the other view showing, one side the centre line, one half a section across the line AB, the other half a section across BC, the other side a side elevation in outside view.

The size, that is, the amount of material required, and therefore the cost, of many electrical machines is determined by the heating or temperature rise which can be allowed to take place. This heating is due to the conversion of electrical into heat energy by (1) the electrical resistance of the conductors, (2) the resistance to changes of magnetism in the iron circuits. The better a machine is ventilated, the less hot it will get, the smaller and cheaper it can be made. The cored holes in the plate arms and through the rim are to facilitate ventilation, cold air coming in through the side webs and passing out at the rim to the parts which require cooling.

Oil-throwers (fig. 98).—At the medium and high speeds at which electrical machinery is run, any oil creeping along the shaft will be thrown off by centrifugal effect into the electrical part of the machine, which may in time cause serious deterioration, ultimately leading to breakdown. It is equally objectionable to have the oil thrown all about the neighbourhood of the machine.

Drawing No. 23A.—Draw to a scale of three-eighths full size the wheel shaft, and make full-size details of the oil-throwers on it.

The idea is to provide faces at right angles to the length of the shaft. Oil travelling along the shaft turns up the perpendicular face and is thrown off the edge by centrifugal force into suitable receptacles. The oil-thrower at F is turned solid on the shaft; the others are loose, to facilitate assembly. Once the magnet wheel has been forced and fixed on the shaft by the two keys indicated, it is not necessary to remove it; hence the thrower at E is fixed on



At D & G Loose Oil thrower fixed by Set Screws

At F Oil thrower turned on Shaft

At E Oil thrower forced on Shaft.

Drawing No. 23.

Scale. 3/4 Full Size

Alternator. Magnet Wheel.

the shaft by forcing it on. At D and G they are fixed by grub-screws and are readily removable.

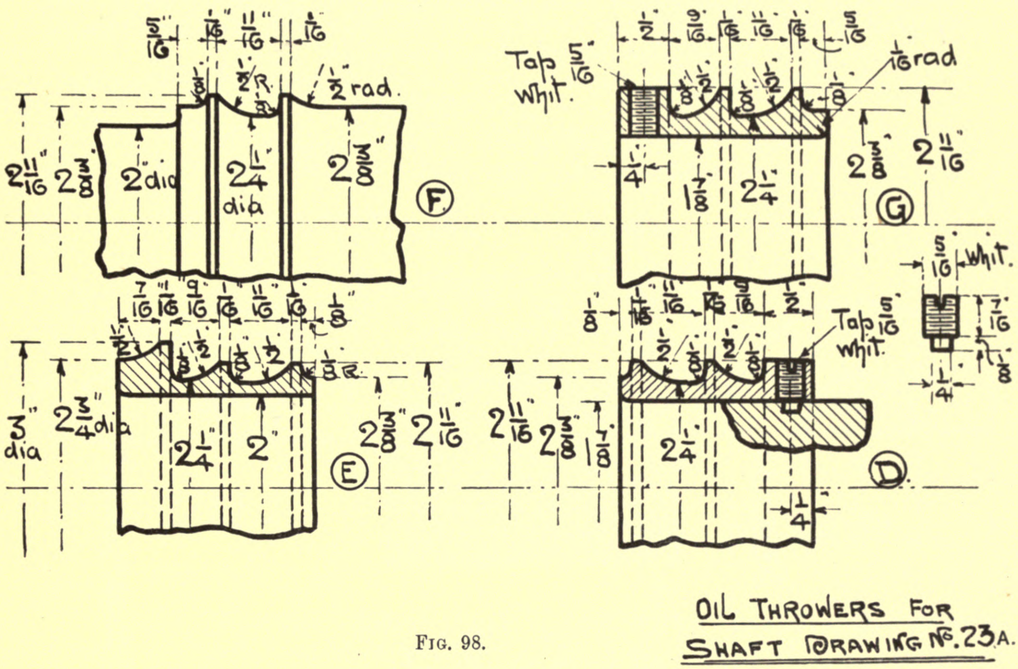


FIG. 98.

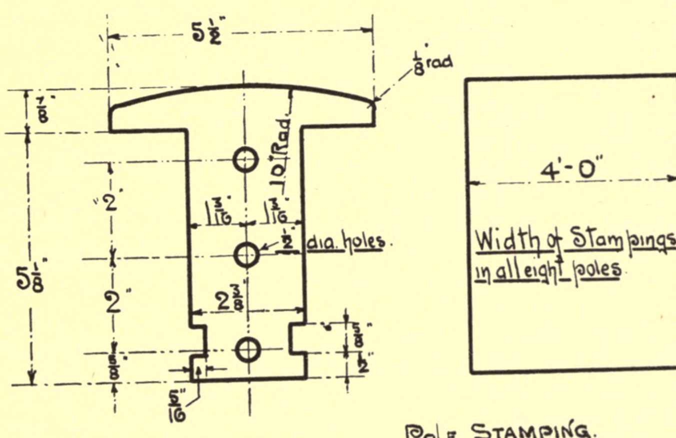


FIG. 99.

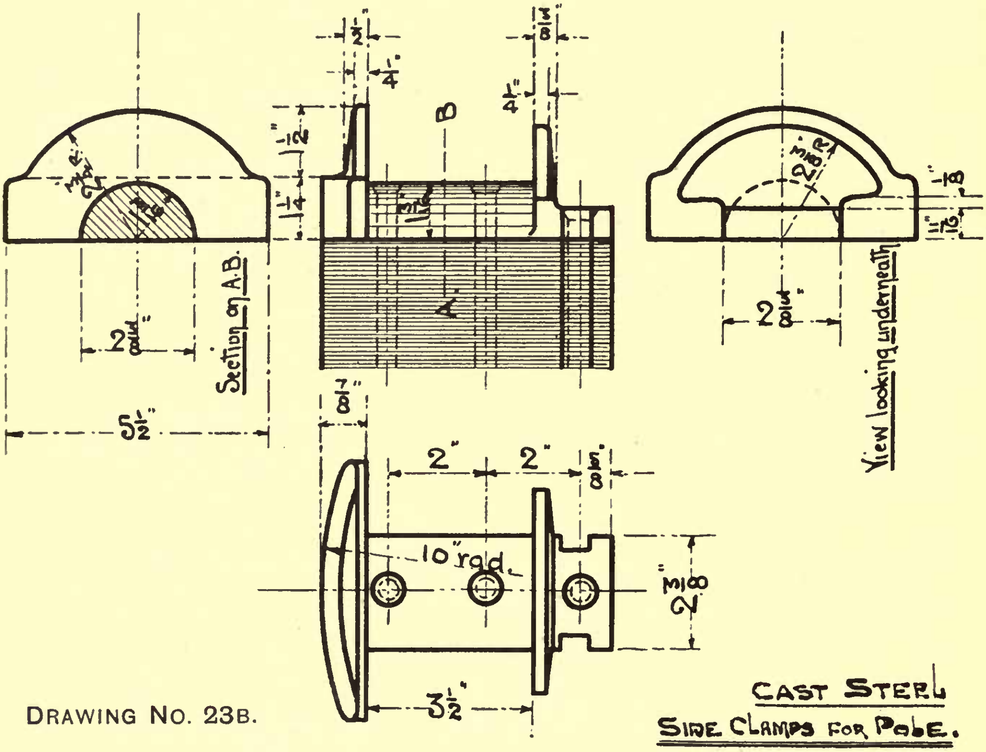
Example.—Make a table giving the shaft diameter, which is accurate, and the bore of the boss for forcing fits, for shafts from 1 to 4 inches diameter.

Magnets.—Each magnet is built up from stampings of the shape shown in fig. 99, made from well-annealed steel sheets 20 mils thick, which have had

paper 1·5 mils thick pasted on one side only. The stampings are built up side by side so as to make a thickness of 6 inches when pressed tightly together and held firmly by the cast-steel side clamps (fig. 100), the whole being held together by the three mild-steel rivets $\frac{1}{2}$ inch diameter, with ends countersunk, and increasing to $\frac{3}{4}$ inch diameter in a length of $\frac{1}{4}$ inch.

Drawing No. 23B.—Draw to a scale of full size a complete pole showing—

An end elevation.
A side elevation, half in section, half in outside view.
A plan looking on the under side.



DRAWING NO. 23B.

FIG. 100.

Each complete pole has its body part insulated by presspahn $\frac{1}{64}$ inch thick wrapped round to form four layers, then four end washers of $\frac{1}{32}$-inch presspahn split and put two on each end. The pole is then swung in the lathe and wound with 939 turns of No. 18[s] standard wire gauge double cotton-covered copper wire (high conductivity for electrical purposes), giving a coil as shown in fig. 101. The wire is wound tight, being well held together by tape during winding, particular care being taken with the end or finishing turn.

When assembled, adjacent coils are connected start to start and end to end, so that poles are magnetised alternately north and south, the two free end leads being cleated to the wheel, and connected to slip-rings mounted on the shaft. See Drawing No. 24.

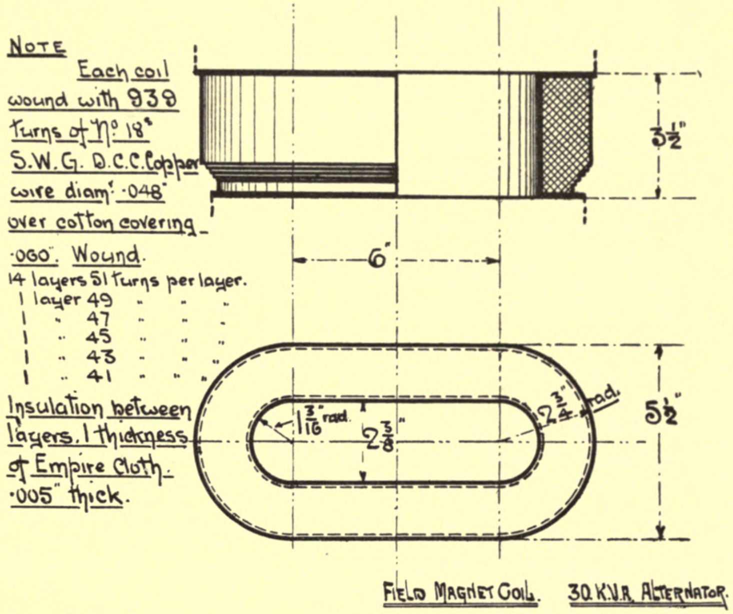


FIG. 101.

Drawing No. 23C.—Draw to a scale of half full size a complete arrangement of the magnet wheel, as indicated by fig. 102, giving—

A front elevation.

A side elevation above the centre line in section across the vertical centre line, below the centre line in outside view.

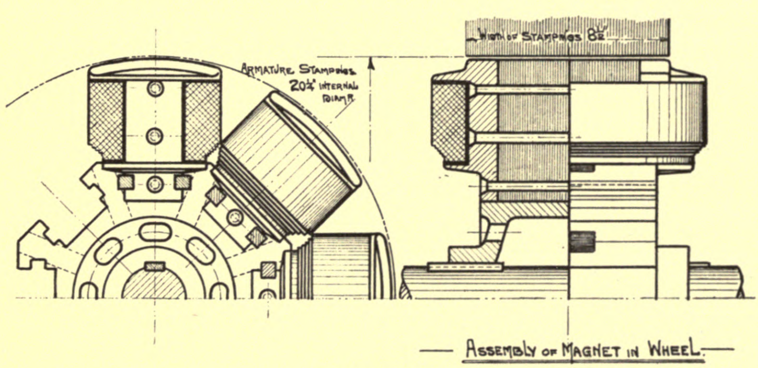


FIG. 102.

Examples—

1. The shaft and rotor making 750 revolutions per minute, verify that the periodicity of the E.M.F. produced in the stator winding is 50.
2. Verify that the mass centre, *i.e.* centre of gravity, of each pole is

·625 feet from the shaft centre, and find the velocity on this circle at 750 revolutions per minute.

3. Verify that the weight of each pole is roughly 75 lbs., made up of: stampings, 45 lbs.; castings, 13 lbs.; winding, 15 lbs.; margin, 2 lbs.
4. Each pole is held to the rim by two $\frac{5}{8}$ inch square steel keys, $7\frac{1}{4}$ inches long when finished, and carefully bedded to be a tight driving-in fit. To find the pull on these keys, when the wheel is rotating, note that—

   Every body in motion tends to move with uniform velocity along a straight line. If the body has to move, say, in a circular path, then some force is necessary to constrain its motion and make it move in that path.

$$\text{Force} = \frac{W}{g} \times \text{acceleration} = \text{lbs.}$$

   For a body moving in a circle the acceleration is velocity squared, divided by the radius of the circle.

$$CF = \frac{Wv^2}{gr} \text{ lbs.}$$

   Examples 2 and 3 furnish the data which are required to complete the example.

5. Set out to a scale of quarter full size a general arrangement of the alternator, taking the stator or frame from the specimen white print, fig. 11; end bearings from Drawing No. 17C, 1; magnet wheel and shaft, Drawing No. 23; and slip-rings from Drawing No. 24. Show a side elevation, above the centre line in section, below in outside view; an end elevation, the left-hand half in section, and the right-hand half in outside view.

ALTERNATOR SLIP-RINGS.

Drawing No. 24.

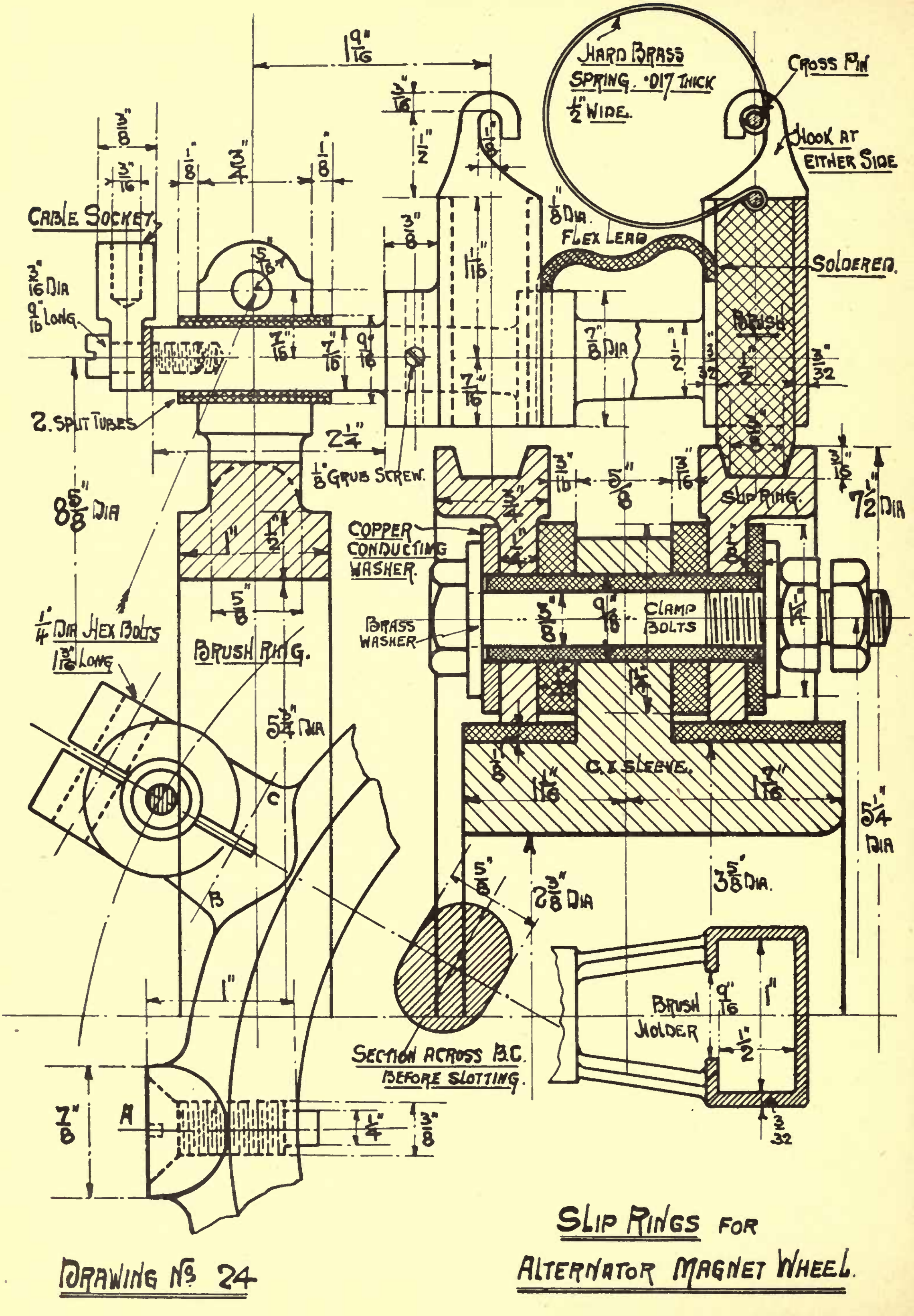
To circulate current through the winding (fig. 101), so as to excite the magnets (fig. 102), some form of rubbing contact is necessary. The slip-rings shown consist of a cast-iron supporting sleeve keyed on the shaft with a $\frac{3}{4}$ inch by $\frac{3}{8}$ inch sunk key, and having six arms equally pitched, bored $\frac{9}{16}$ inch for the fibre insulating tube, and holding the clamping bolts. Four of the bolts clamping the slip-rings to the sleeve are entirely insulated from the sleeve and rings by fibre bushes, washers, and rings. The other two, diametrically opposite each other, have an extra nut, and take the end connections from the pole windings, these connections being cleated to the magnet wheel, one of these bolts being in metallic contact with one slip-ring, the second with the other slip-ring, through the brass and copper washers shown.

Two copper gauze brushes under spring pressure bear on each ring, supported in two long and two short brush-holders, which are connected to the external exciting circuit and carried by the cast-iron brush-ring, being insulated from it by the split-fibre bush inserted in the split boss gripping the holder. The brush-ring has four split bosses, the one on the vertical and one 60° to the left carrying short brush-holders, the other two, 60° and 120° to the right, carrying long brush-holders. The brush-ring is usually carried from the inside end of the end bearing (refer to fig. 74), which is collared up and turned, the ring being bored to fit on, and then fixed by three equally spaced countersunk screws as shown at A.

Draw to a scale of full size the views shown in fig. 103—

A side elevation above the centre in section below in outside view.
An end elevation of the brush-ring.
Half the end elevation looking in at slip-ring side of the arrangement.

Example.—Make fully dimensioned detail drawings as indicated in fig. 104.


HARD BRASS SPRING ·017 THICK
½" WIDE.
CROSS PIN
HOOK AT EITHER SIDE
CABLE SOCKET
3/16" DIA 9/16" LONG.
⅛" DIA. FLEX LEAD
SOLDERED.
BRUSH
2. SPLIT TUBES
⅛" GRUB SCREW.
8⅝" DIA
COPPER CONDUCTING WASHER.
SLIP RING.
7½" DIA
BRASS WASHER
CLAMP BOLTS
¼" DIA HEX BOLTS 1 3/16" LONG
BRUSH RING.
5¾" DIA
C.I. SLEEVE.
5¼" DIA
2⅜" DIA
3⅝" DIA.
BRUSH HOLDER
SECTION ACROSS B.C. BEFORE SLOTTING.
DRAWING No. 24
SLIP RINGS FOR ALTERNATOR MAGNET WHEEL.

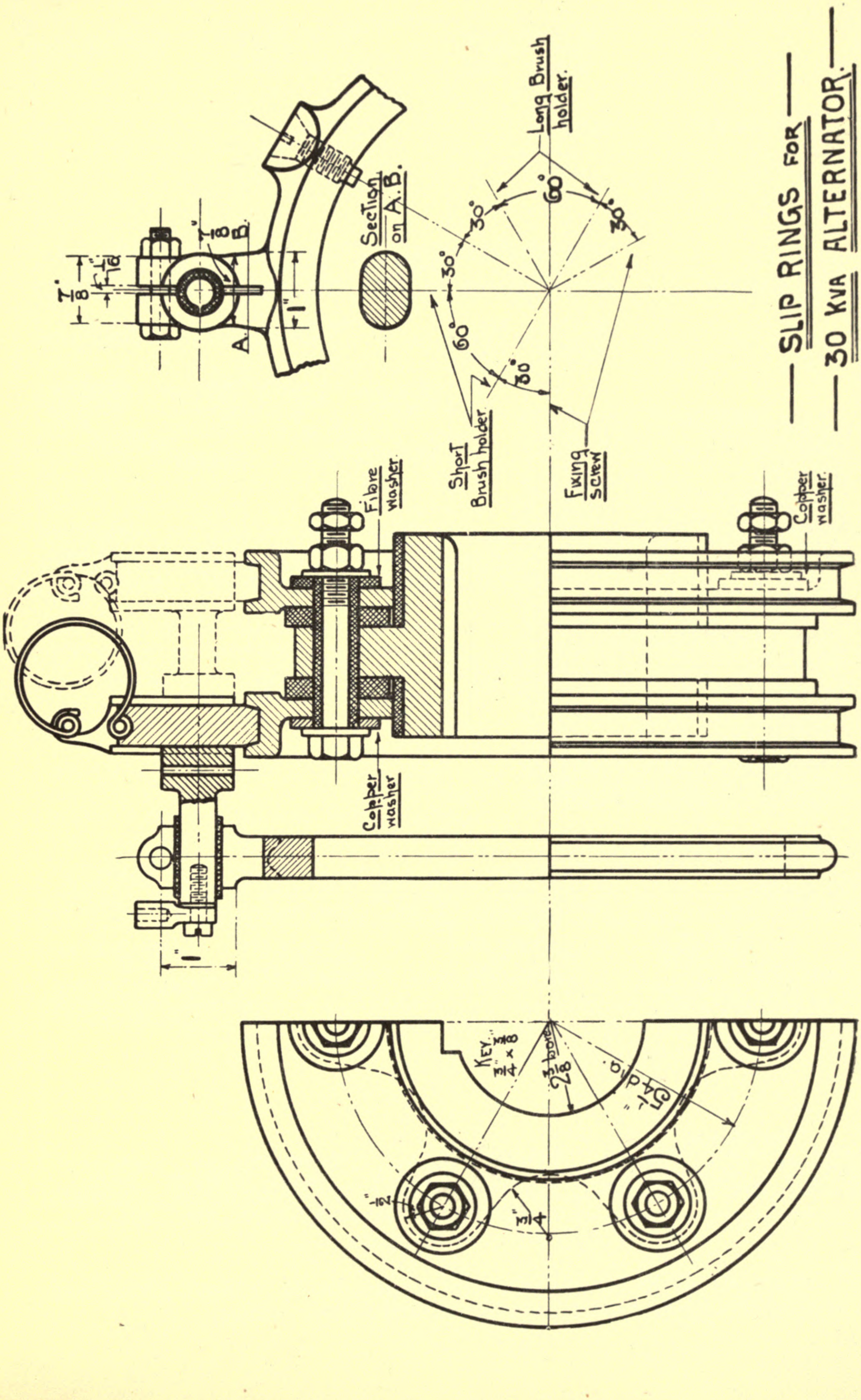

SLIP RINGS FOR
30 KVA ALTERNATOR.
Section on A. B.
Long Brush holder.
Short Brush holder
Fixing screw
Fibre washer.
Copper washer.
Copper washer.
Key $\frac{3}{4}$" x $\frac{3}{8}$
$2\frac{3}{8}$ bore
A
B

Fig. 103.

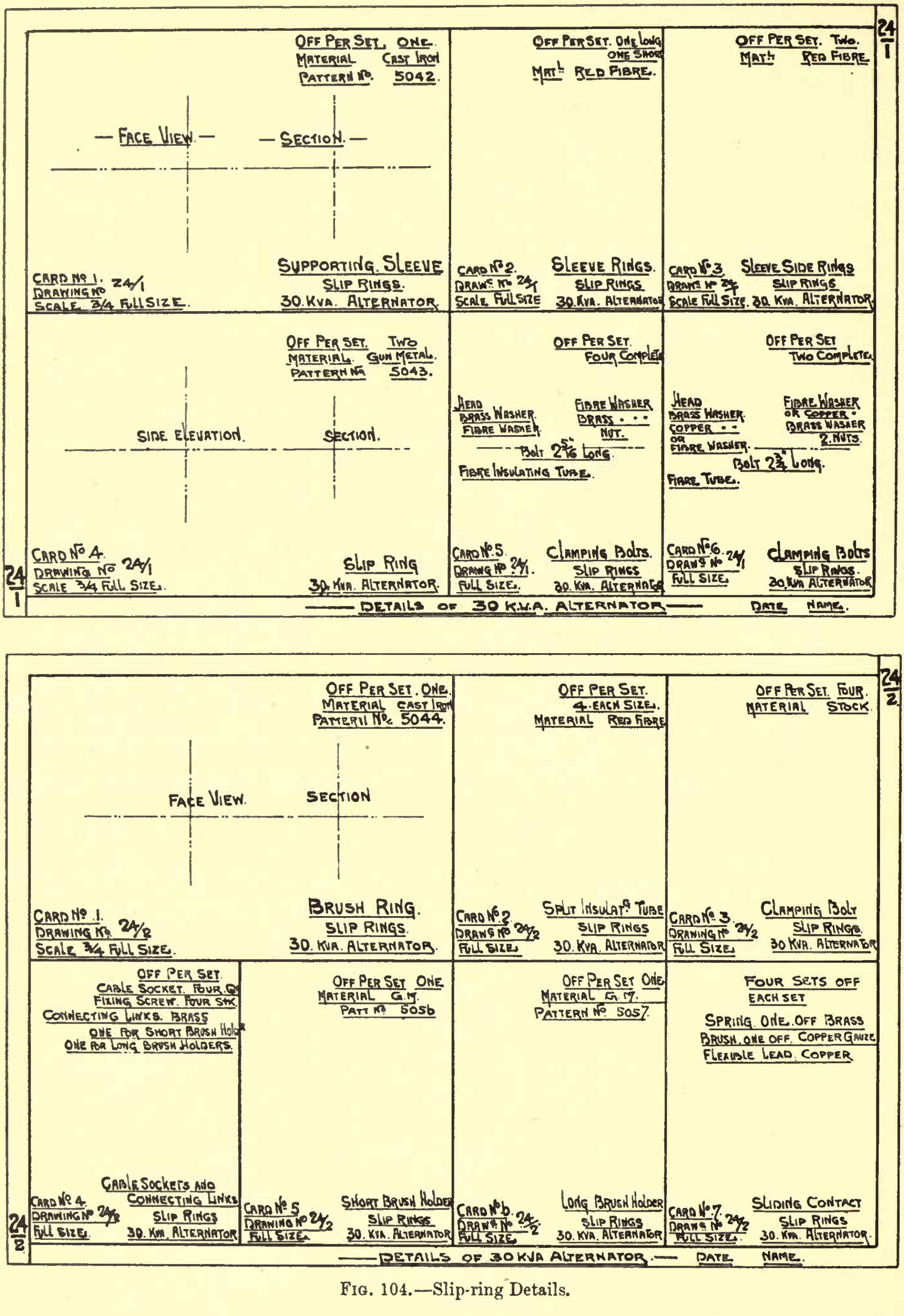


FIG. 104.—Slip-ring Details.

Example.—Write out a schedule for all the details required, giving card number, description, material, number off, and pattern number.

COMMUTATOR.

Drawing No. 24A.

AN essential and important detail of a continuous-current dynamo or motor is the commutator, which enables current uni-directional in character to be obtained and used. It consists of a ring of copper segments on which the brushes connected to the external circuit rub. As shown, the gun-metal V ring is forced on the shaft and driven by the sunk key. To insulate the current-carrying bars from the shaft, and thus from the frame of the machine, the presspahn ring is slipped on the V ring, then the coned mica ring and the tubular mica ring. The commutator bars with strips of mica between, thus insulating them from each other, are slipped into the V groove, and the end coned and tubular mica rings put in position, the whole being clamped and wedged up tight by the gun-metal end nut, which is retained and locked in position by the grub-screw. Each commutator bar has its end slotted so that the armature conductors can be readily sweated up to it.

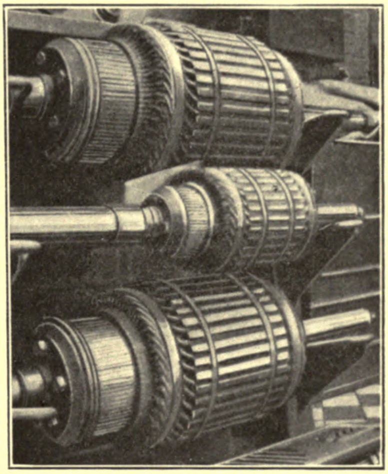
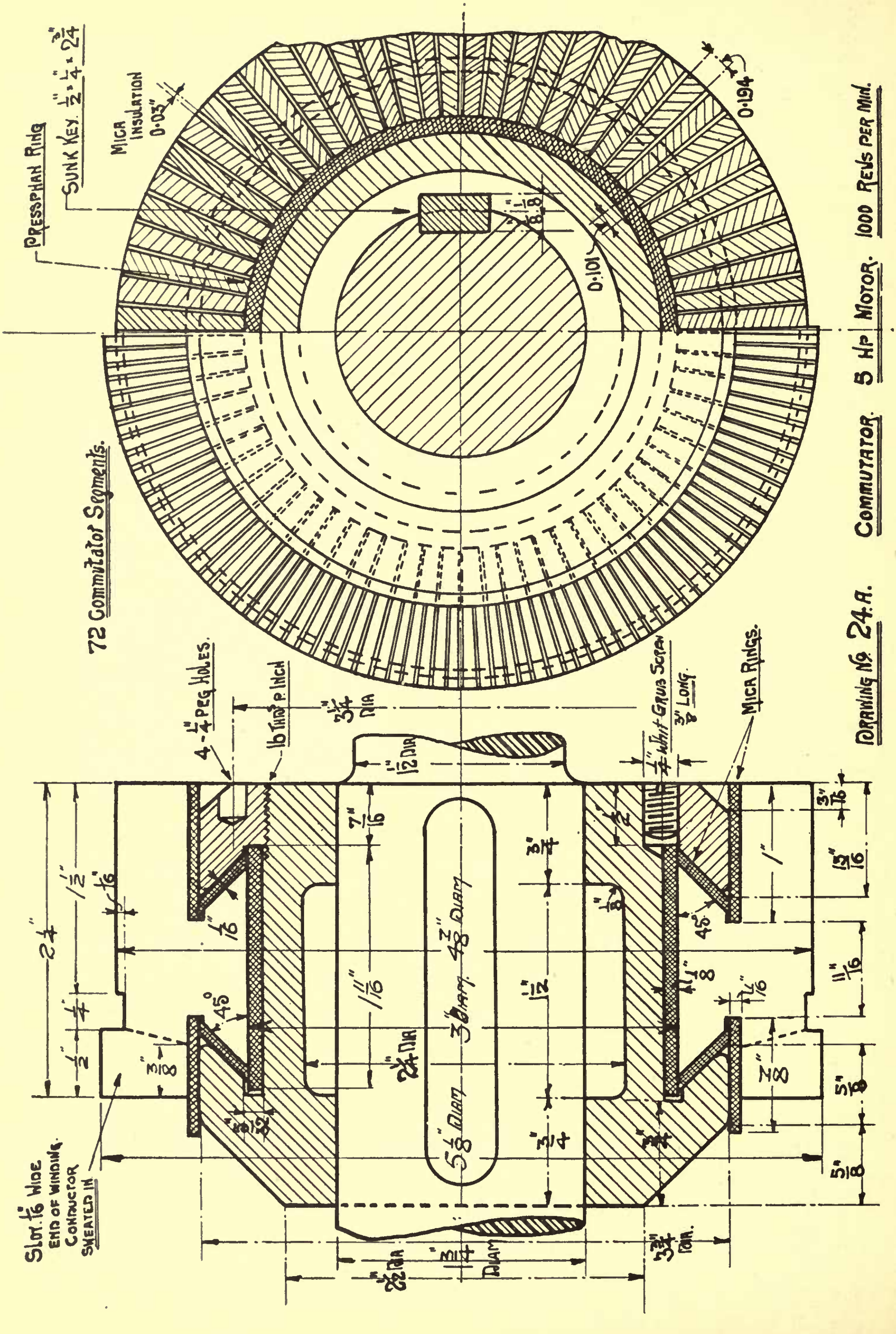


FIG. 105.—Motor Armatures.

Make a drawing to a scale of full size, showing the general arrangement, and separately each detail of the commutator fully dimensioned.

Examples—

1. State what machining is necessary on each of the above details.
2. Explain how a commutator may be skimmed up in position, and say what are the causes which make this trueing up necessary, and how they may be reduced so as to have minimum effect.



Drawing No 24.A.
Commutator.
5 HP Motor.
1000 Revs per Min.
72 Commutator Segments.
Presspahn Ring
Sunk Key
Mica Insulation
Mica Rings.
Peg Holes
Whit Grub Screw
Slot 1/16" Wide
End of Winding
Conductor
Sweated In

CONNECTING-ROD FOR STEAM ENGINE.

Drawings Nos. 25 *and* 25A.

In a steam or gas engine, to convert the backward and forward motion of the piston into rotary motion of a shaft, so that energy may be more easily transmitted, a crank connecting-rod mechanism is used. In the connecting-rod the stress is alternately a compression and a tension, any slack in the joints tending to give a knock each time the stress is reversed. Keeping the bearings full of lubricant tends to deaden the noise.

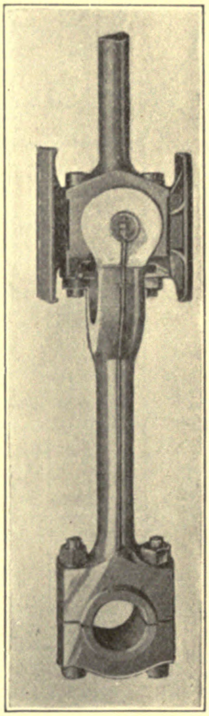


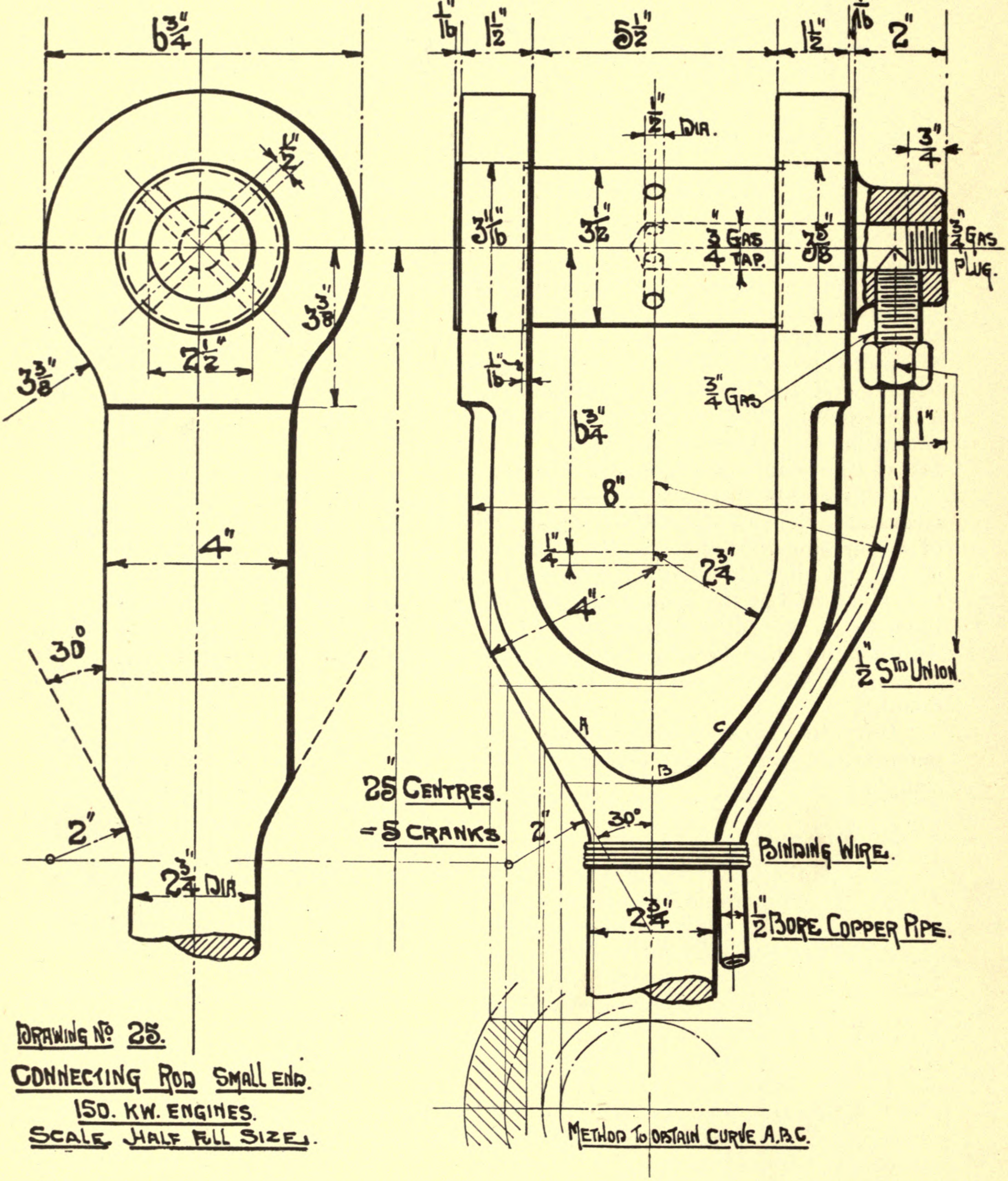
Fig. 106.—Connecting-rod.

The position of the piston in the cylinder, and its end clearances, depend upon the length, that is, the centres, of connecting-rod, and any adjustments made for wear should not alter the distance between the centres. Acting as a strut, and at the same time oscillating, its dimensions have to be carefully determined. The rod is machined from a mild steel forging, the pin, bolts, and nuts turned from mild steel bar, and the bearing made of hard white metal.

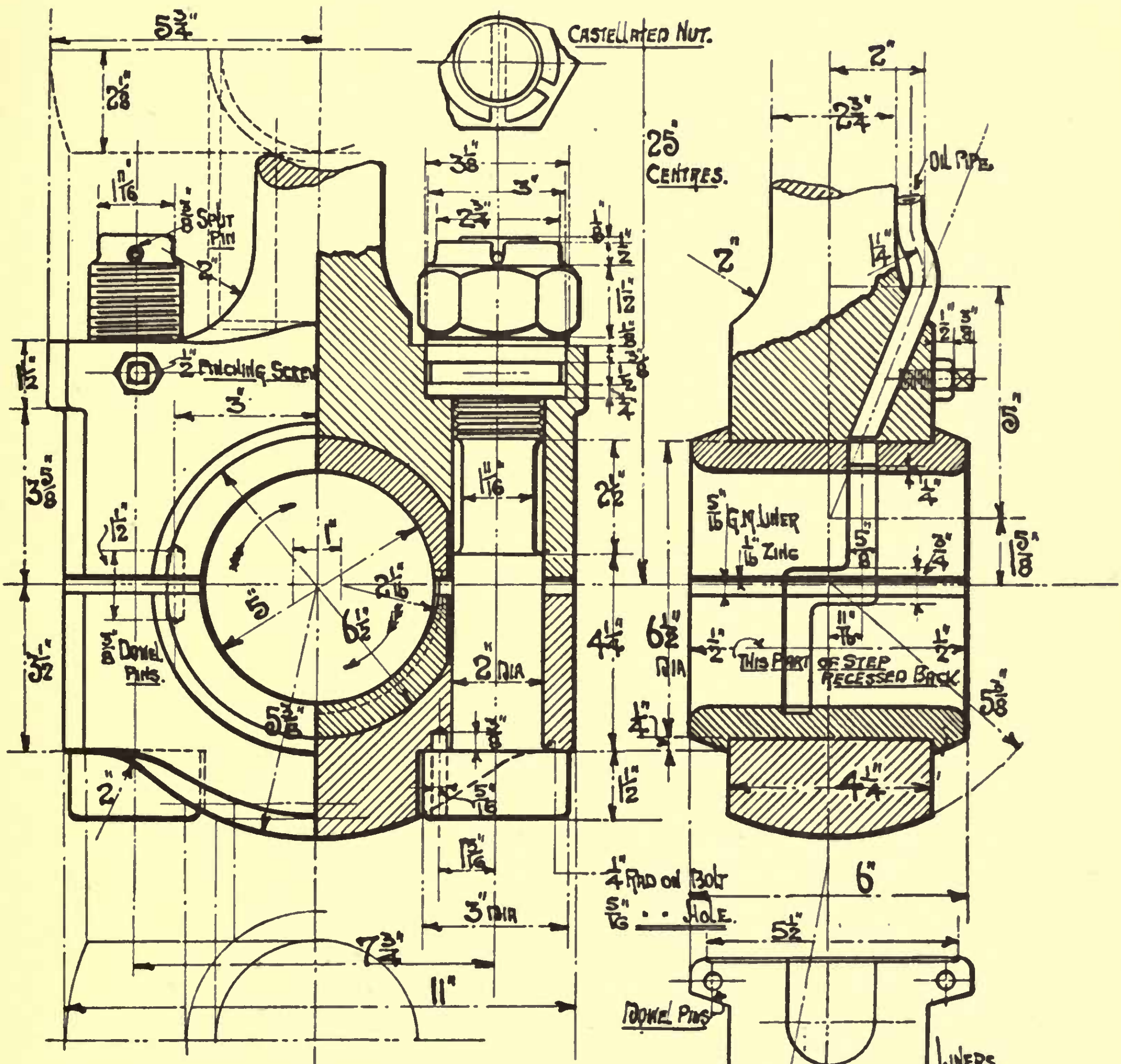
Draw to a scale of half full size, obtaining all curves geometrically, a front elevation and a plan of the complete rod.

Examples—

1. Make a sketch of the forging from which the rod would be machined, giving dimensions so as to allow for necessary machining.
2. The rod and bolts being made from the same quality material, compare the sectional area of the two bolts and the rod.
3. Write out an explanation as to how the cross-head pin is lubricated. Note its journal bearing is fixed in the end of the piston-rod.
4. On the drawing, write out a description of the method used to obtain the face curves formed by the round rod meeting the flat and forked ends.



DRAWING NO 25.
CONNECTING ROD SMALL END.
150. KW. ENGINES.
SCALE HALF FULL SIZE.



DRAWING No. 25A. CONNECTING ROD. BIG END.

CRANK-SHAFT.

Drawing No. 26.

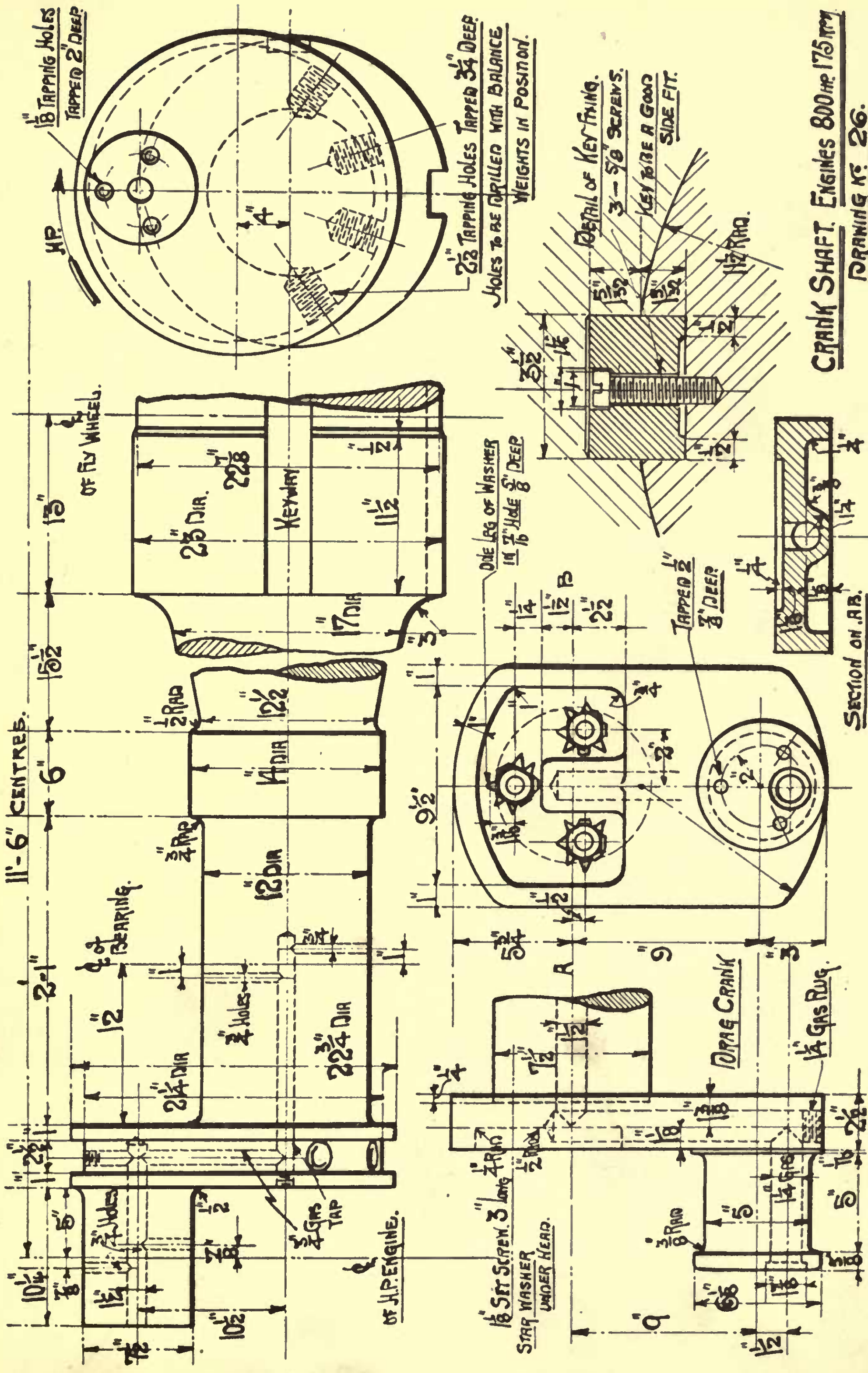
THE crank-shaft forging is made from mild steel having a tensile strength of from 28 to 32 tons per square inch, with an elongation of 30 per cent. in 2 inches. The drag or fly-crank, made of cast-iron, is fitted to the crank-pin and drives the oil-pump, 3-inch stroke, which lubricates the bearings. The oil, after straining, enters the drag crank through a union joint, surfaces held tight by a spring, on the centre line of the shaft; passing along, it lubricates the crank-pin, the main bearing, and if required the eccentric. The oil pressure at the crank-pin enables it to be taken through and along the connecting-rod to lubricate the crosshead pin and the guide bars. The oil pressure required, 24 to 25 lbs. per square inch, is not by any means the maximum pressure on the bearing, but only sufficient to force the oil into the bearing when the pressure is reduced on one side. On the return stroke the time is not sufficient to squeeze the oil from between the surfaces before the pressure is again reduced and the oil supply renewed.

The fly-wheel is keyed on the shaft by two keys at right angles, and the low-pressure crank-pin at the other end follows behind the high-pressure pin in the direction of rotation by 90°. The crank balance weights are fixed by the screws indicated.

Draw to a scale of 2 inches to 1 foot, fully dimensioned, a side elevation and an end elevation of the complete shaft, showing the drag cranks in position.

Examples—

1. Sketch, with dimensions, a cast-iron crank, and explain how it is fixed on the shaft.
2. Sketch and describe the correct way to fix a loose crank-pin into the crank.
3. What is the function of the crank balance weight fixed as indicated?
4. Estimate the weight of material in the shaft shown.
5. What machining allowances would be given on the forging from which shaft is machined?


CRANK SHAFT. ENGINES 800 HP 175 RPM
DRAWING No. 26.
DETAIL OF KEY FIXING.
3 - 5/8" SCREWS.
KEY TO BE A GOOD SIDE FIT.
HOLES TO BE DRILLED WITH BALANCE WEIGHTS IN POSITION.
SECTION ON A.B.
DRAG CRANK
11'-6" CENTRES.
OF FLY WHEEL.
OF H.P. ENGINE.
BEARING.
KEYWAY
STAR WASHER UNDER HEAD.

PISTON-ROD AND CROSSHEAD.

Drawing No. 27.

In the crank connecting-rod mechanism, some arrangement must be provided to relieve the piston-rod of a bending action due to the resultant force on the piston-rod connecting-rod joint. This usually consists of slippers attached to the piston-rod end, sliding on and supported by guide bars attached to the engine framing.

On the *out stroke*, so long as the piston-rod pushes the connecting-rod, the thrust is downwards; but before the end of the stroke is reached, due to exhaust port closing, and pre-admission of steam, with the idea of bringing the moving parts to rest with the least amount of shock, the effective pressure on the piston-block is reversed, the connecting-rod pulls on the piston-rod, and the direction of the thrust becomes upwards. Also, when steam is shut off and the engine is turning and slowing down, the thrust is upwards. Thus, for a forward or clockwise direction of rotation the main thrust is downwards,

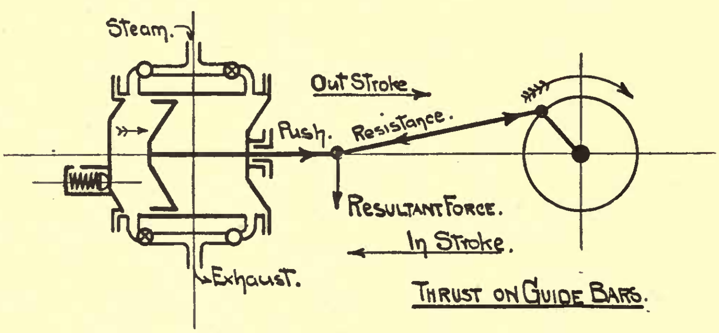


Fig. 107.

but there is also an opposite thrust to be taken into account. For this reason the bottom or main slipper often has the largest sliding area.

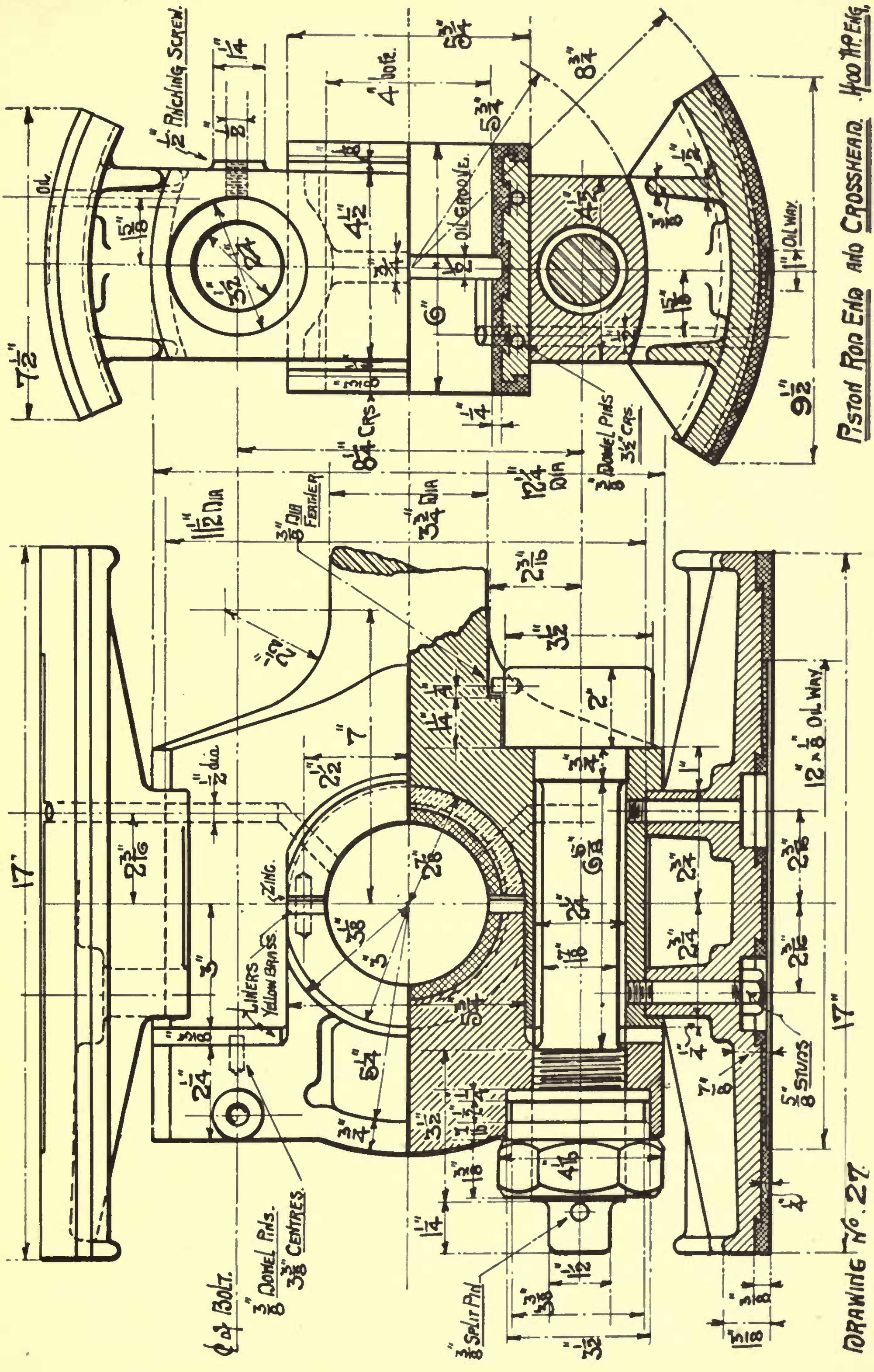
Draw to a scale of half full size, showing completely—

- A front elevation.
- A side elevation.
- A plan half in section across the centre line of the piston-rod, and half in outside view.

The slippers and guides are lubricated from the crosshead pin by the oil-ways shown, the slippers being lined with white metal. If heating should take place, the white metal will run out and so avoid the scoring which would take place with cast-iron on cast-iron. To obtain accurate centring, the slippers are turned up when fixed to the rod end. The crosshead pin bearing is of hard white metal run in the cast-steel cap and the cast-steel step.

Examples—

1. Make detail drawings, fully dimensioned, of the separate parts making up the complete crosshead.
2. What is the object of necking down the body part of the bolts?
3. Compare the sectional areas of the piston-rod, crosshead pin, and the two bolts.


Piston Rod End and Crosshead. 400 H.P. Eng.
Drawing No. 27.
1/2" Pinching Screw.
Oil Groove.
Oil Way.
3/8" Dowel Pins 3 1/2" Crs.
3/8" Dia Feather
Liners Yellow Brass.
Zinc.
3/8" Dowel Pins. 3 3/8" Centres.
℄ of Bolt.
3/8" Split Pin
5/8" Studs
12" × 1/8" Oil Way.

GOVERNOR.

Drawing No. 28.

THE speed of the engine during the time of one revolution is kept within defined limits by the use of the fly-wheel. To keep the speed constant over longer time-intervals is the function of the governor. Take the case of a steam engine: if the load increases, the mean effective pressure on the piston must be increased, while if the load falls off the pressure must be reduced; otherwise the speed would fall or rise until the resistance equalled the effort. A governor regulates the pressure on the piston by operating on (1) the point of cut-off of the valve, (2) the throttle valve. In a gas engine it regulates the gas admission, and in an oil engine the quantity of oil. Fig. 108 is an illustration of the governor.

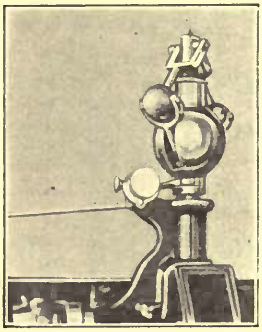


FIG. 108.—Governor.

Draw to a scale of full size—

A front elevation showing the central weight in section.
An end elevation.
A sectional plan through the lower arm pins.

The governor depends for its action upon the effect of centrifugal force. As the speed rises the balls tend to fly outwards, and for a simple governor, that is, one without central control, the height of the cone of revolution of the balls is given by

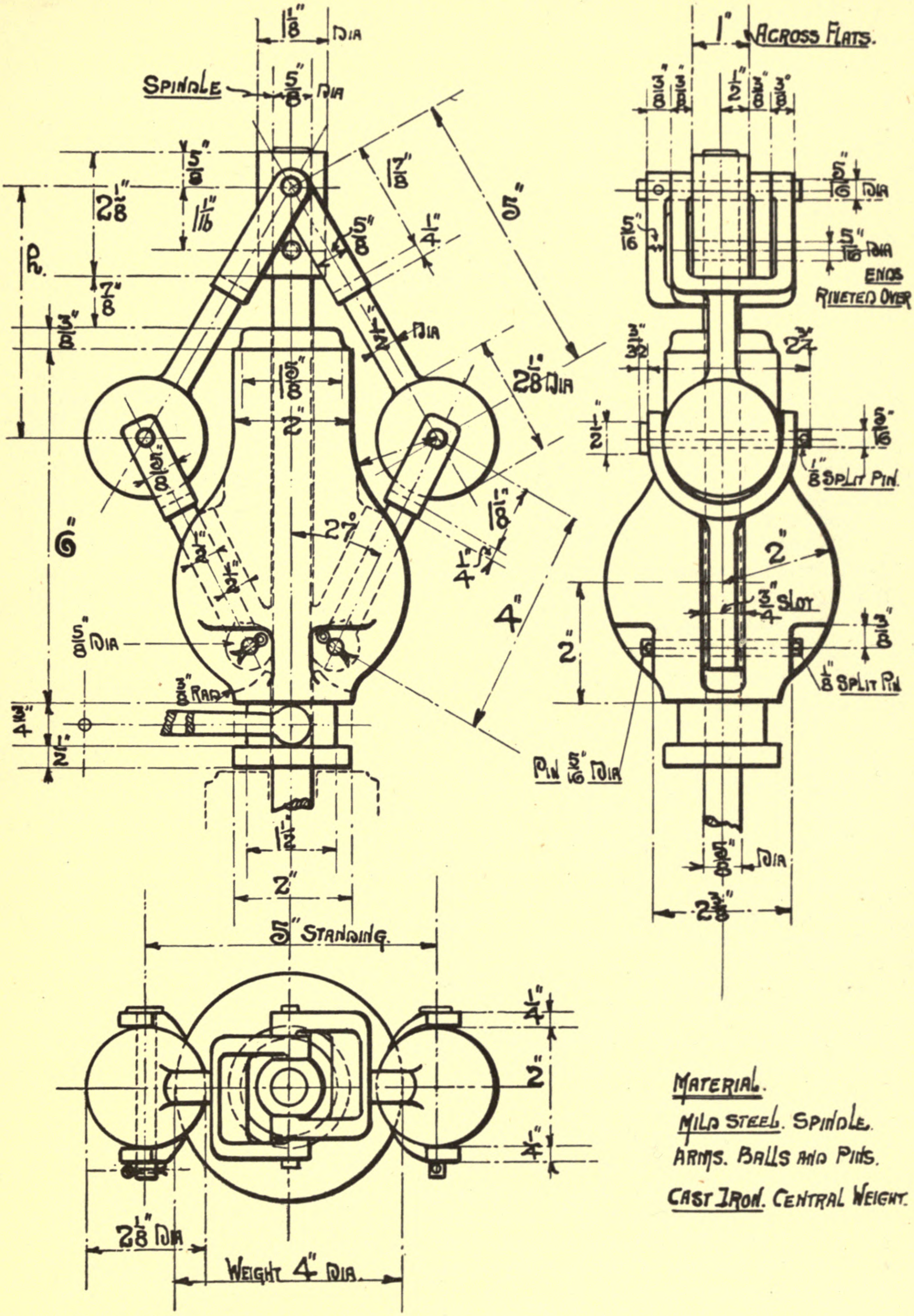
$$h = 35{,}250 \div N^2 \text{ inches.} \quad N = \text{revolutions per minute of balls.}$$

For a central loaded governor in which the central weight is lifted twice as fast as the balls rise,

$$h = \frac{35{,}250}{N^2} \times \frac{A + 2B}{A} \text{ inches.} \quad \begin{array}{l} A = \text{weight of both balls in lbs.} \\ B = \text{central weight in lbs.} \end{array}$$

Examples—

1. In this example, what is the ratio between the weight of one ball and that of the central weight?
2. What speed, in revolutions per minute, will just bring the central weight against the top stop, that is, $h = 3{\cdot}875$ inches? Verify this value for h by reference to the drawing, and setting out the ball motion.
3. What speed, in revolutions per minute, just begins to lift the governor off the bottom stop (neglecting friction)? $h = 4{\cdot}325$ inches.
4. What is the object in using a spring instead of a central weight?



MATERIAL.

MILD STEEL. SPINDLE.
ARMS. BALLS AND PINS.
CAST IRON. CENTRAL WEIGHT.

DRAWING No. 28.
SCALE FULL SIZE.

— LOADED GOVERNOR. —

STOP VALVE.

Drawing No. 29.

THE function of a valve is to regulate and, if necessary, interrupt the flow of energy along a main. Take the governor, Drawing No. 28: when the effort is greater than the load, the speed rises, the balls fly out, the clutch on the sliding sleeve is raised, and by suitable link-work may operate a valve, and so restrict the flow of steam to the engine cylinder, adjusting the effort to the load and the constant speed required. Such a valve is called a throttle valve (Drawing 29A), as by restricting the flow it reduces the steam pressure.

To entirely cut off or regulate the steam supply by hand a **stop valve** as here shown is used. It consists of a cast-steel body into which a gun-metal seating is forced; a disc, mushroom, or seated valve closing on this seat being operated by the square thread screw and hand-wheel.

Draw to a scale of quarter full size—

A front elevation, half in section, half in outside view.
A side elevation.
A plan, half in section through centre line of valve, half in outside view.

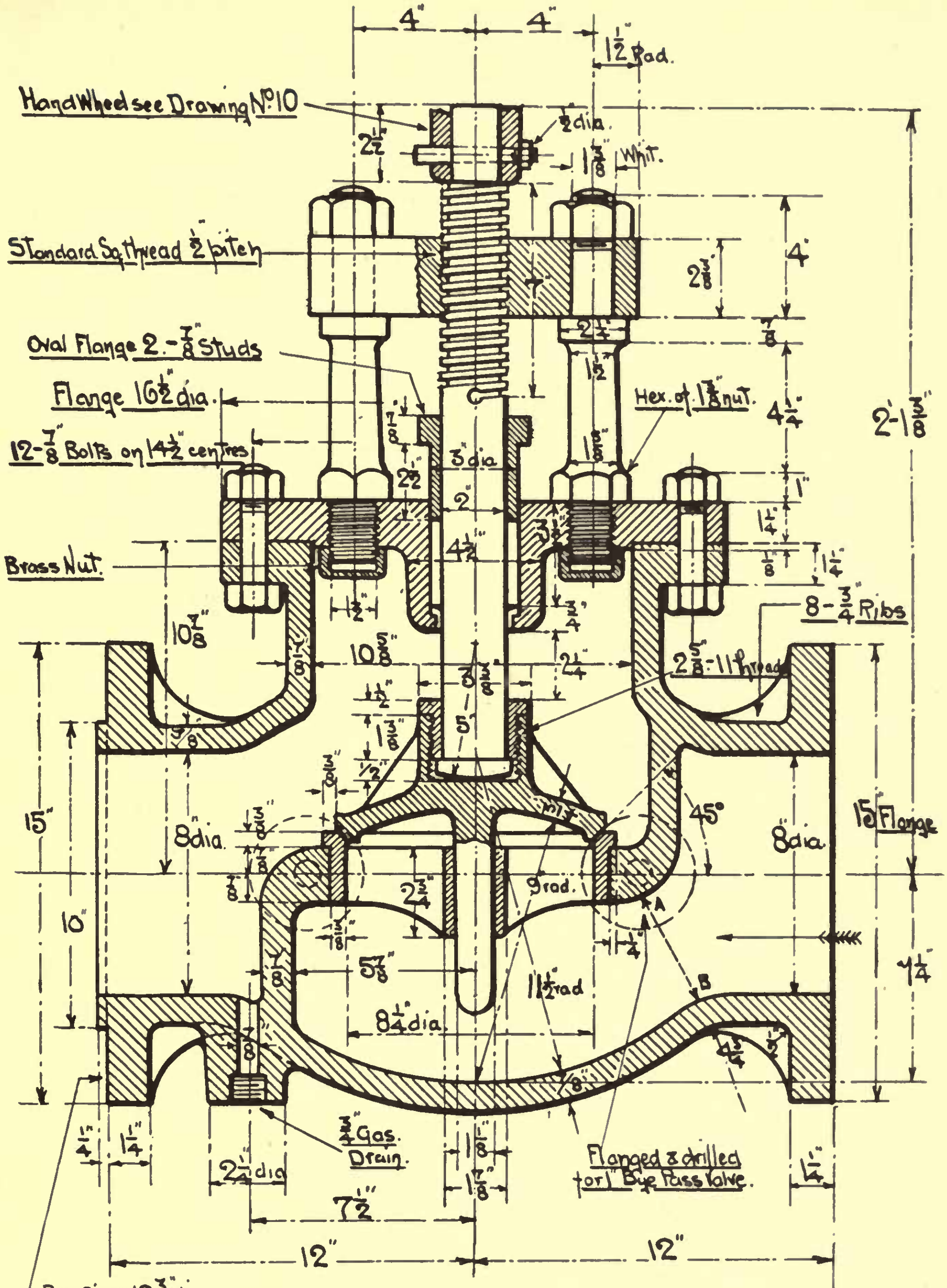
The great difficulty, using steam at high pressure and temperature, is to maintain a tight joint, a small leak developing by grooving into a serious one. Mushroom valves are liable to stick on their seats, due to temperature effects. Thus, if valve is firmly shut when cold, steam entering under side of valve expands seating and disc more than body casting, and disc jams into seat. Steam entering on top side of valve expands the spindle, jamming the valve into its seat or the operating spindle in its nut.

Preferably the valve and its seat should be able to expand independent of the valve box, and should not warp, soften, or deteriorate at high temperatures.

Large valves above 5 inches diameter should be by-passed, and all valves should be opened slowly and with caution, as sudden opening may produce a shock sufficient to rupture the main.

Examples—

1. For each flange, what is the distance from centre to centre of bolt, expressed as so many times the bolt diameter?
2. The theoretical lift of a valve, corresponding to a full-bore opening, is one-quarter of the valve diameter. From your own observations, say if it is usual to open a valve to this extent.
3. For further examples refer to page 217.



8" DIA STEAM STOP VALVE.

FOR 200 LBS. PER SQ INCH.

DRAWING No 29.

SCALE - ¼ FULL SIZE.

THROTTLE VALVE.

Drawing No. 29A.

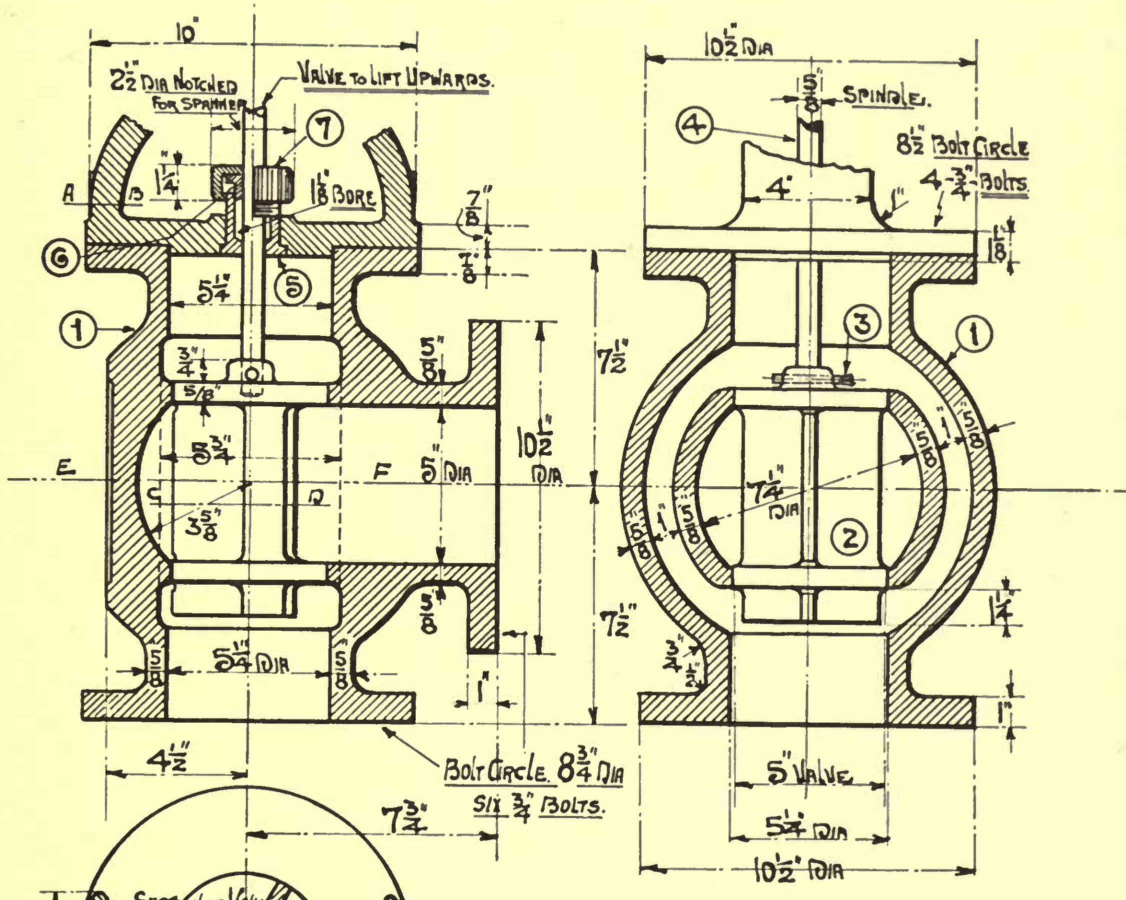
In its simplest form this is of the piston type, as shown, which is in perfect equilibrium and does not offer any resistance to the action of the governor, but has the disadvantage of soon becoming leaky, and cannot be adjusted to a tight fit. A modification is to make the valve seating in the form of a cage let into the valve casing.

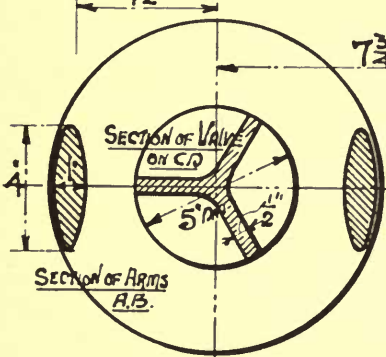
Draw to a scale of half full size—

An outside front elevation.
A side elevation in section including the stuffing box.
A plan in section across the line EF.

Examples—

1. The valve motion is derived from a governor similar to that shown in Drawing No. 28. Make a line diagram indicating relative positions of the governor balls and the throttle valve.
2. State the objections which may be raised against the use of a packed gland to maintain the valve spindle steam-tight as it slides through the cover. Sketch and describe an alternative arrangement in which the use of packing is dispensed with.
3. Pipe flanges are made standard for pressures up to 55, 125, 225, or 325 pounds per square inch. Make a table showing bore of pipe, number of bolts, diameter of bolts, diameter of pitch circle, thickness of flange, and flange diameter, for pipes from $1\frac{1}{2}$ to 12 inches diameter, and suitable for a working pressure of 200 pounds per square inch.





— THROTTLE VALVE. —

REF NO	DESCRIPTION	MATERIAL	NO OFF	PATT NO	REMARKS
1	VALVE CASING	C. I.	ONE.	752.	
2	VALVE.	G. M.	ONE	753	
3	SPLIT TAPER PN.	M S	ONE	-	STOCK
4	SPINDLE	M S	ONE.	-	
5	STUFFING BOX	G M.	ONE	754	
6	GLAND	G M	ONE	755	
7	FORCING NUT	G M.	ONE	756	

ALTERATIONS.

DRAWN BY. TRACED BY. CHECKED BY DATE.

DRAWING No 29. A.

SCALE HALF FULL SIZE.

CYLINDER RELIEF VALVE.

Drawing No. 29B.

In a reciprocating engine the moving parts come to rest at the end of each stroke. To facilitate this, the exhaust valve is closed before piston has completed the stroke, and steam valve does not open until piston is just about on the end of the stroke. For economy in working the clearance volume between piston and cylinder end is reduced to a minimum. Water may be present in the cylinder, due to priming or condensation. If the volume of water at end of stroke, when all valves are closed, is greater than clearance volume, it can only escape by lifting valves off their seat, forcing itself past the piston, or doing damage unless a relief valve (see fig. 107) is fitted to provide an outlet.

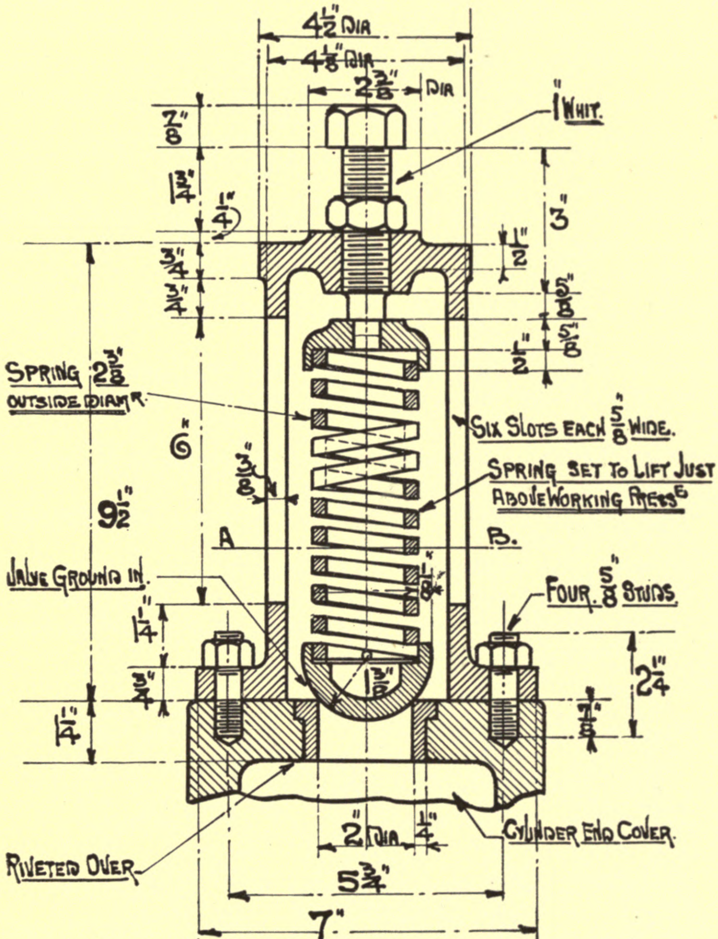
Draw to a scale of three-quarters full size—

A sectional elevation.
A sectional plan across AB.
An end elevation correctly projected.

The use of relief valves reduces cost of maintenance on valves and pistons, prevents broken and leaky joints and broken cylinder ends.

Examples—

1. How would you arrange for machining the ball valve? How is the valve ground in to its seat?
2. Detail the valve seat, showing how it is machined to facilitate riveting over after being forced into position.
3. The spring casing is made of gun-metal. Make a rough sketch of the pattern and core box from which the mould for the detail would be prepared.
4. Make a sketch of the pattern from which the gun-metal valve would be cast.



DRAWING No. 29.B.
SCALE ⅓ FULL SIZE.

CYLINDER RELIEF VALVE.

PISTON VALVE.

Drawing No. 29C.

Draw to a scale of half full size the piston valve and liner given, showing—

1. Piston valve complete with rings in position,
2. Liner,

in each case by a front elevation and a plan, each being half in section and half in outside view.

To pass steam through the cylinder, in such a way that the engine is made automatic in its working, valves are fitted and operated on a definite cycle (fig. 109):—

1. Steam admission: commencing with the crank at A, continuing until the crank reaches some position B.
2. Expansion. The cylinder is closed, the steam expanding doing work while the crank moves from B to C.
3. Exhaust. The cylinder is put in communication with the exit; the steam, having done its work, is passed out, to do further work in other cylinders, into the atmosphere, or into the condenser, while the crank-pin moves from C to D.

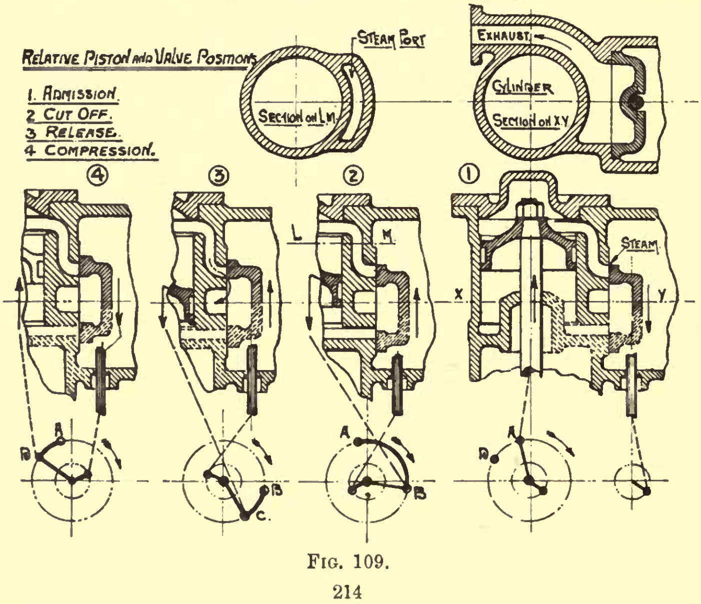
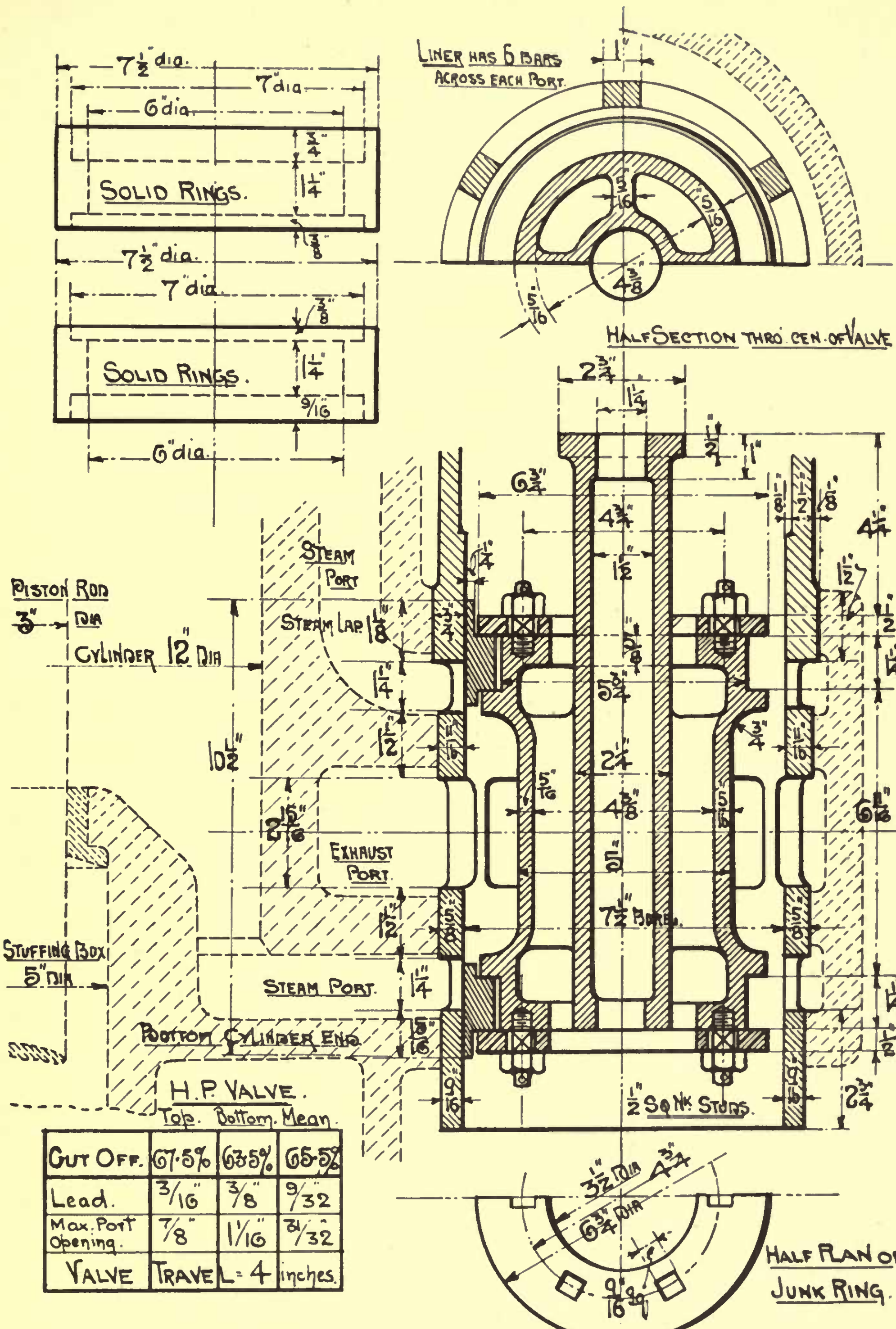


Fig. 109.



	Top.	Bottom.	Mean.
CUT OFF.	67·5%	63·5%	65·5%
Lead.	3/16"	3/8"	9/32"
Max. Port Opening.	7/8"	1 1/16"	31/32"
VALVE	TRAVEL = 4 inches.		

DRAWING No 29.c.

Scale Half Full Size.

PISTON VALVE FOR 12" x 10" STEAM CYLINDER.

4. Compression. With crank at D, the valve closes the cylinder to exhaust; the vapour trapped is compressed up into the end of the cylinder, helping to bring the moving parts to rest and reducing the volume of steam required to fill the clearance spaces, when the crank-pin gets to A and the valve opens to steam admission.

What has been considered for one side of the piston is equally true of the other side, the actions taking place being just the same, but one stroke later. The valve may be operated by an eccentric (see Drawing No. 9, Card No. 2), by cams, or by gearing.

For a high-pressure cylinder a piston valve is usually made two-thirds cylinder diameter, and half cylinder diameter for a low-pressure cylinder.

The simplest form of valve is the flat D slide valve, which has the disadvantages of friction due to the heavy pressure carried, warping due to temperature changes and the use of flat containing surfaces. To remove these a balanced D valve is sometimes used, or more often a valve of the piston type, with usually spring rings to maintain it steam-tight.

For superheated steam, balanced drop valves have advantages as regards lubrication, warping, and tightness over piston valves.

Examples—

1. Set out a simple flat D slide valve, suitable for a 12-inch cylinder, to the following dimensions:—Centre line of spindle 3 inches from valve face; spindle, $1\frac{1}{4}$ inches diameter; steam port, $10\frac{1}{2}$ inches long, 1 inch wide; width of bridge, $\frac{3}{4}$ inch; width of exhaust, $2\frac{1}{4}$ inches; outside or steam lap, $\frac{5}{8}$ inch; inside or exhaust lap, $\frac{1}{16}$ inch; valve travel, $3\frac{1}{4}$ inches; lead, $\frac{1}{32}$ inch. Show the valve spindle, and indicate clearly how it is attached to the valve.
2. Explain, using a sketch, how the pressure on the back of a simple D slide valve may be relieved.
3. What advantages are obtained by using separate steam and exhaust valves? Sketch in detail a cylinder in which such valves are used.
4. Show how, by means of a valve diagram, the crank positions at which admission, cut-off, release, and compression take place can be determined from the valve and eccentric particulars.

OIL-PRESSURE REGULATING VALVE.

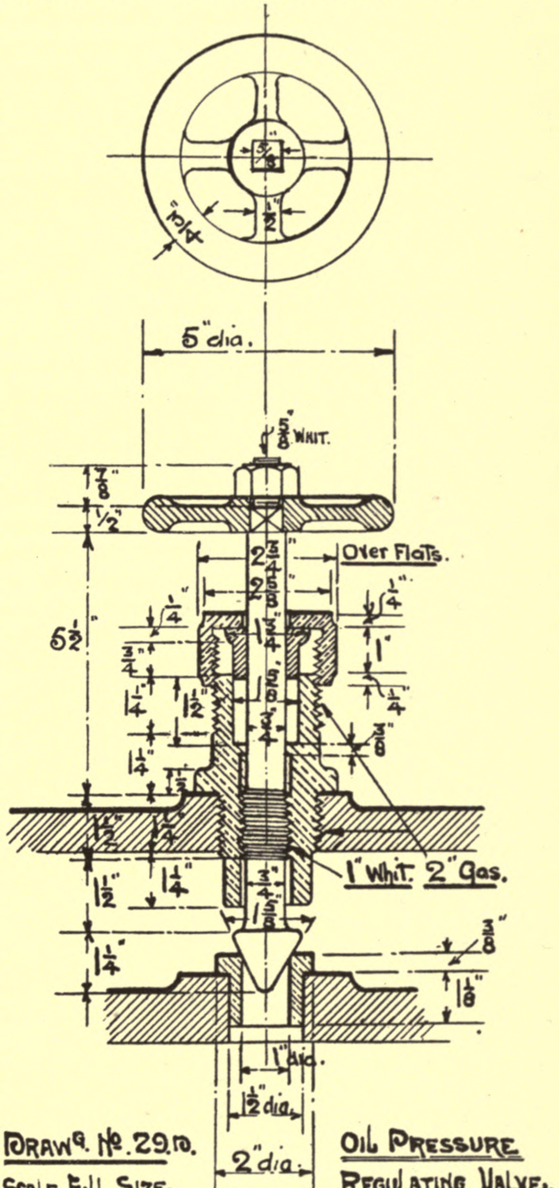
Drawing No. 29D.

To regulate the passage of a liquid a pin valve as shown is used. The actual example is used to regulate the oil-pressure in the forced lubrication system of a steam engine, keeping the pressure steady about 25 lbs. per square inch. To prevent damage if the oil-pressure should rise, a relief valve, to go at 75 lbs. per square inch, is fitted.

Draw to a scale of full size the valve, spindle, and containing casting only, showing a section, an outside end elevation, and a plan.

Examples—

1. Drawing No. 29. On a line parallel to AB project the section made by a plane containing the line AB, and state the area of the opening in square inches. Compare this area with that of the pipe.
2. Drawing No. 29. Make fully dimensioned detail drawings of all the details required for the stop valve. Arrange your drawings for a card system.
3. Limiting the steam velocity to 5000 feet per minute, what diameter of stop valve is required for a cylinder 12 inches diameter, the piston speed being 500 feet per minute?
4. Drawing No. 29. What is the stress in lbs. per square inch area at the base of the threads, on the bolts holding down the body cover?



5. Sketch a sluice valve. State its advantages and disadvantages as compared with a mushroom valve.
6. Show that, with a valve the same diameter as the steam-pipe, the theoretical lift of the valve to obtain unrestricted opening is one-quarter the diameter.
7. Sketch a balanced seated valve, *i.e.* a drop valve. What are its advantages when superheated steam is used?
8. Under what conditions would studs be used instead of bolts for a flanged joint? Sketch an example. Show how to find the pitch and diameter of the studs required.
9. Drawing No. 29B. The spring is screwed down to open just above the working pressure, and for its dimensions—

$$E = \frac{\text{free length} - \text{length fully compressed}}{\text{number of coils in spring}} = \frac{\cdot 75}{10} \text{ inch.}$$

D = diameter of coil = 2 inches.

W = load to produce compression E = working pressure $\times$ valve area $= 150 \times \cdot 7854 \times 2 \times 2 = 475$ lbs. say.

C = constant = 30 for square steel.

d = side of square section in sixteenths.

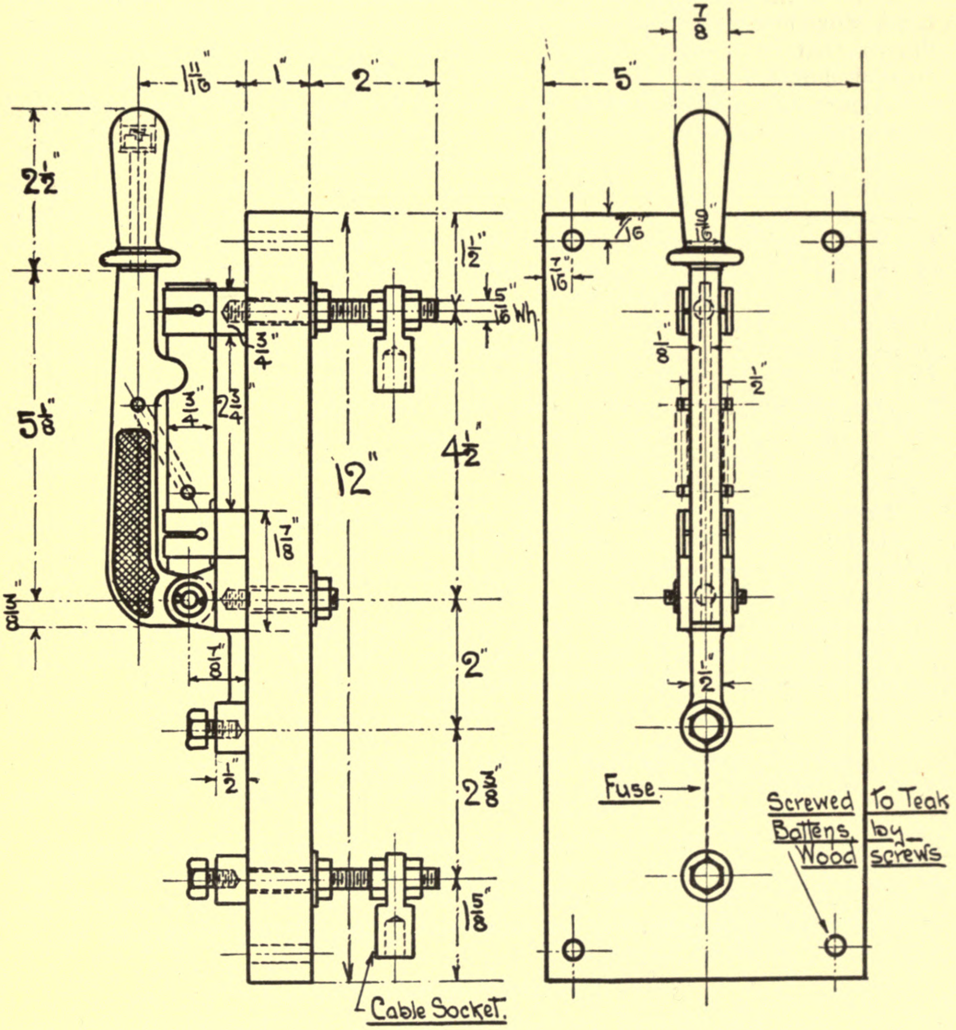
$$d^4 = \frac{D^3 W}{EC}.$$

$$d = \tfrac{5}{8} \text{ inch.}$$

10. Drawing No. 29D. Pin valves are also used for regulating the flow of water under high pressure. Describe, with necessary sketches, a valve box suitable for operating a hydraulic press, and explain how the valves are geared together to make certain that they are opened and closed in the correct order.

Drawing No. 29E.

For an electric main the apparatus fulfilling the function of a valve is called a switch. It may be used for simply disconnecting, or it may have to break a circuit while current is flowing, in which case it should be made with



DRAWING No. 29.E
SCALE. FULL SIZE.

50 AMP. SINGLE POLE
QUICK BREAK KNIFE SWITCH.

a quick break. It must have a full-on and a full-off position, and no intermediate positions should be possible. Given the single-pole switch and details:—

Make, to a scale of full size, a fully dimensioned arrangement drawing of a double-pole, 50-ampere, quick-break knife switch; take horizontal centres $2\frac{1}{2}$ inches apart.

It is mounted on a specially selected hard slate base, free from metallic veins, black stove enamelled and polished on face and edges. The blade is of hard-drawn, that is, wrought, copper. The current density in any part carrying current should not exceed 800 to 1000 amperes for copper, and 300 amperes per square inch of cross section for gun-metal castings. The surface density across contact surfaces varies from 75 to 250 amperes per square inch. The jaw contacts are ground in, and laminated for big sizes. To obtain a quick break, the handle comes free, extending the side springs, the blade being retained in the jaws by friction, until the backed-off edge A bears against the blade, and the handle and blade move as one. When the blade gets free of the jaws, the side springs pull it back close up to the handle with a click, and the quick break is obtained. To get the off position, the bottom back corner of the blade is made square, and by butting against the hinge casting gives a definite off position. Switches, after carrying their full-load current for six hours, should not attain a temperature greater than 40° F. above the surrounding atmosphere. For heavy currents the hinge pivot should not be relied upon, but separate jaws fitted as in this example; the contact jaws must be tight and elastic, but all cutting and undue wear of the sliding surfaces is to be avoided.

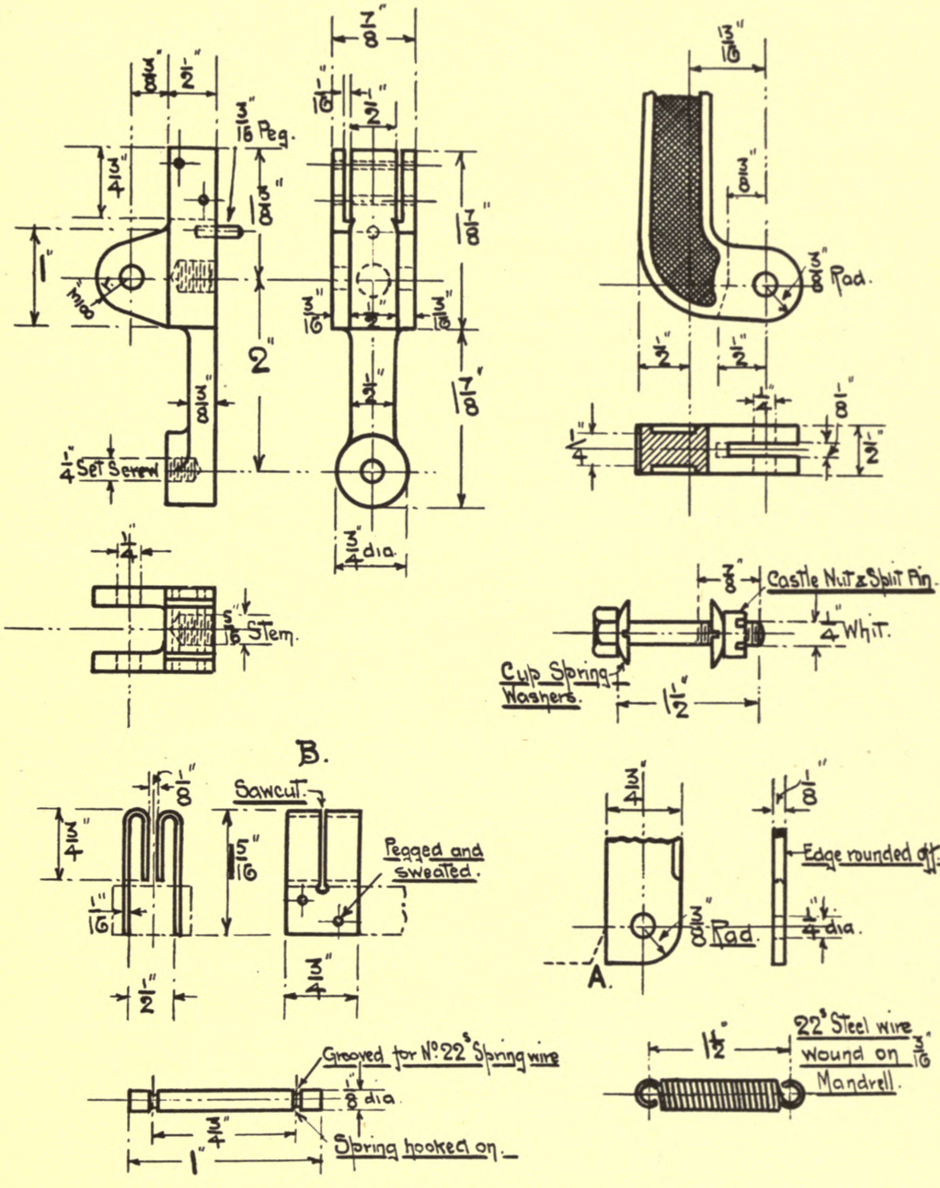
Fuses.—A fuse is a safety device, protecting a circuit against heavy rushes of current. It consists of a strip of metal having a low melting-point, or of reduced section compared with the rest of the circuit, so that in case of heavy currents it melts or is destroyed and the circuit is opened. A fuse should be rigidly clamped in position, using spring washers, so that racking due to temperature changes will not work it loose. The distance between the fuse terminals varies with the current and the voltage of the circuit.

Examples—

1. What is the object of splitting the jaw contacts as shown at B?
2. Why is it necessary to have a quick-break switch when opening a circuit under load?
3. Why are large switches tipped with carbon at the breaking point?
4. Circuits below 75 amperes are usually fused with wire. What diameter of wire would you use for the 50-ampere circuit if the fuse is to blow at one and a half times the normal current, *i.e.* 75 amperes, given:

$$\text{Fusing current} = \text{constant} \times \text{diameter}^{1\cdot5}?$$

The value of the constant for copper is 10,000, for tin 1500, the diameter being in inches.



DETAILS FOR 50 AMP. SWITCH.

FIG. 110.

WHEEL GEAR.

Drawing No. 30.

If wheel teeth are to gear together without undue noise, the teeth on the two wheels must be so formed that the pitch line velocity of the two wheels is always the same. This means that the normal through the point of contact of two teeth must always pass through the point K (fig. 111), which is called the pitch point. To obtain this, faces and flanks of the teeth are made with curves of definite form, *i.e.* **cycloidal** or double-curve teeth, **involute** or single-curve teeth. The usual proportions for wheel teeth are given in fig. 112. Most teeth are now cut, and to the proportions given as new. For cast teeth the tooth thickness is $\frac{5}{11}$ and the space $\frac{6}{11}$ of the pitch, the difference, $\frac{1}{11}$, measured

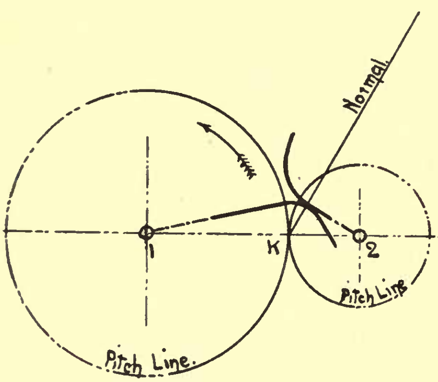


Fig. 111.—Normal Passes through Pitch Point.

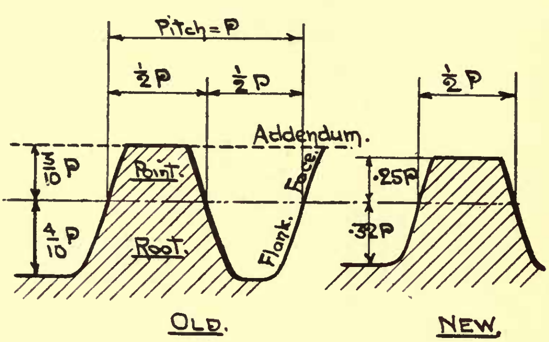


Fig. 112.—Proportions of Wheel Teeth.

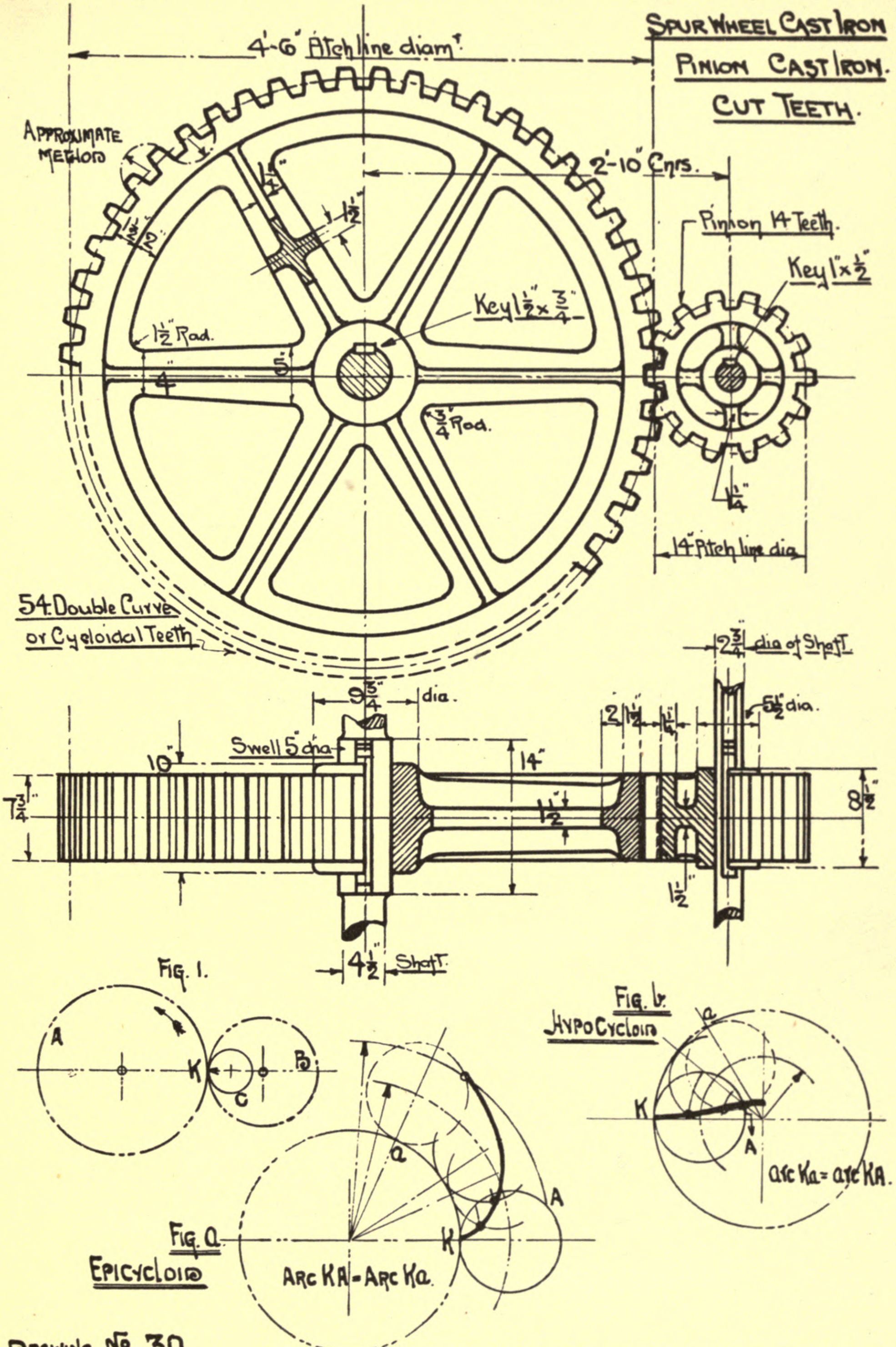
along the pitch line, giving a clearance, called blacklash, and before use the teeth are simply cleared of sand and grit by filing.

Draw to a scale of 2 inches to 1 foot the spur-wheel and pinion.

Pitch line diameter of wheel, 54 inches; of pinion, 14 inches.
Number of teeth in wheel, 54; in pinion, 14.
Width of teeth, 2·5 times pitch. Teeth modified proportions.
Rolling circles used to generate the shape of the teeth to be equal to the radius of each wheel in diameter respectively, therefore giving radial flanks to the teeth of both wheel and pinion.

Set out full size the profile of one tooth for each wheel.

Rolling Circle.—Let the wheel A rotate, and drive the wheel B; the rolling circle C roll on A and B so that the point of contact remains at K.



DRAWING No. 30.

SCALE 2" = ONE FOOT.

SPUR WHEEL AND PINION.

A tracing point on the circle C starting at K will describe a curve on the surface of A, also a curve on the surface of B. The curve obtained by C rolling on the outside of A is shown in fig. *a*, and that obtained by rolling C inside B is shown in fig. *b*.

If the faces of teeth on A and the flanks of teeth on B are made with these curves, the condition for correct driving is satisfied.

Similarly, a circle rolling inside A and outside B gives the curves for the flanks of teeth on A and the faces of teeth on B.

As the diameter of the rolling circle increases, the points of the teeth become more parallel in thickness, and inside of tooth gets more space. When diameter of rolling circle equals radius of wheel the flanks become radial; with a rolling circle greater than the radius of the wheel we get mangle teeth which are weak at the roots.

For two wheels of any set to gear together, the same diameter of rolling circle must be used for tracing the flanks and faces of all the wheels, and this diameter is usually the radius of the smallest wheel.

The minimum number of teeth to be used with cycloidal gear is 12 for the smallest wheel, and the pitch line speed should not exceed 50 feet per second.

Involute Teeth.—Imagine the rolling circle to increase in diameter until it becomes a straight line: the curve traced by a straight line rolling on a circle is an involute (fig. 113), and teeth having this curve for their profile are called involute or single-curve teeth.

As the straight line cannot roll inside the circle, the teeth would be without flanks. To get these, the line of contact is drawn through K, making an angle (angle of obliquity) of 15° with the common tangent, and tangent circles drawn to this line. Involutes described by a straight line rolling on these circles are suitable for wheel teeth. To get the necessary clearance at the bottom of the teeth, the lower part of the tooth is then made radial. The form of tooth obtained is stronger than the cycloidal form, and has the advantage of

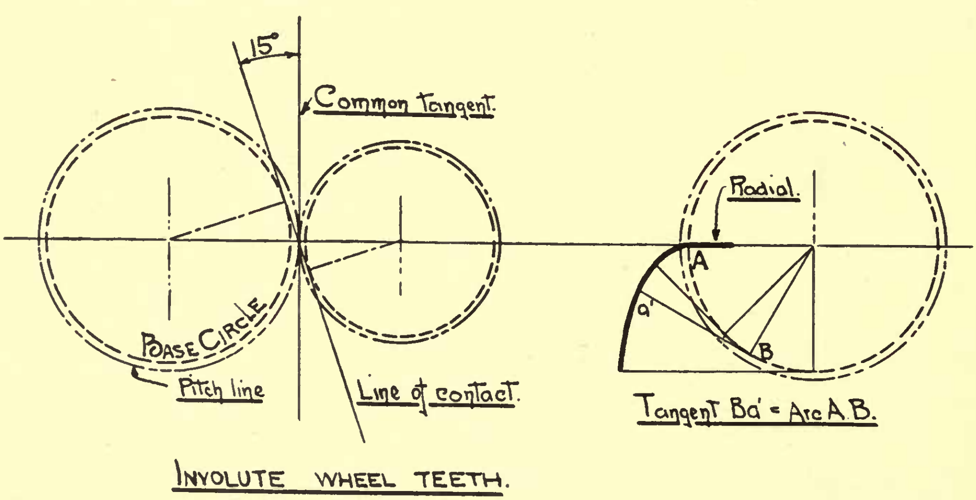


Fig. 113.

gearing correctly when the wheel centres are not accurately spaced. The smallest number of teeth to be used in any wheel is 25. Cycloidal teeth only gear correctly when the wheel centres are accurately spaced.

Examples—

1. If a circle rolls along a straight line, a tracing point on the circle describes a path called a cycloid. Set out full size the profile of a *rack* tooth, pitch 1 inch, rolling circle 2 inches diameter.
2. A wheel $8\frac{1}{4}$ inches diameter has 24 teeth; the pinion has 12 teeth; the rolling circles being 3 inches and $1\frac{1}{2}$ inches diameter respectively. Set out the profile of one wheel, and one pinion tooth.
3. What are the different grades of files used, from rough to dead smooth? Should a file be recut? Why is a hand-cut better than a machine-cut file?
4. What are mortice-wheel teeth? Give a sketch showing how they are fixed in position. Are they used in the wheel or in the pinion, and why?

BEVEL GEAR.

Drawing No. 30A.

Two shafts, axes inclined and intersecting, may be connected by tooth wheels, and drive with an accurate velocity ratio. The pitch cones (fig. 114) will roll together, but will not transmit heavy power. To obtain definite driving, teeth are formed on a portion of each cone by drawing the perpendicular cones, and producing the profile of the teeth by circles or a straight

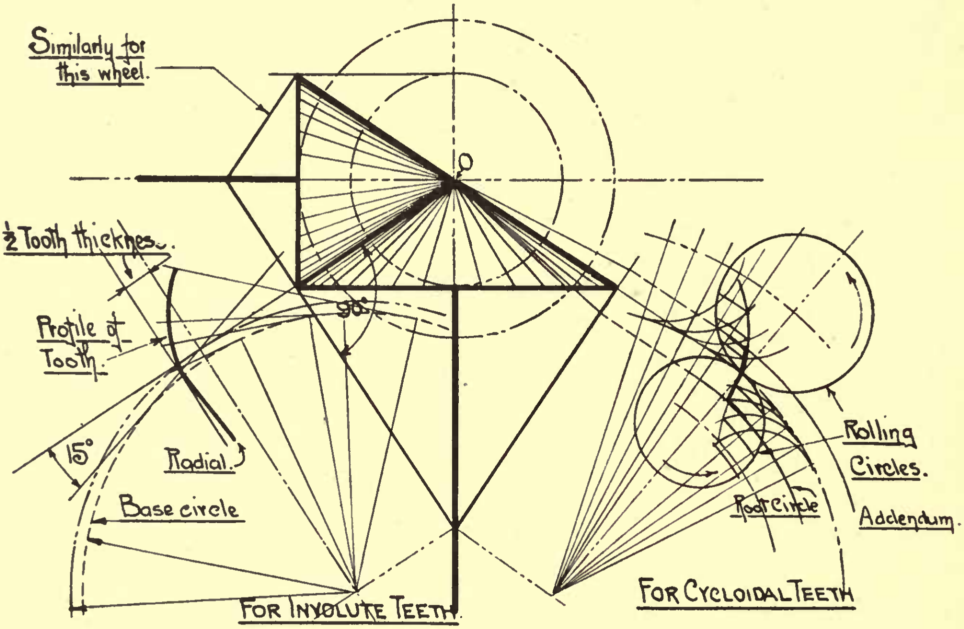


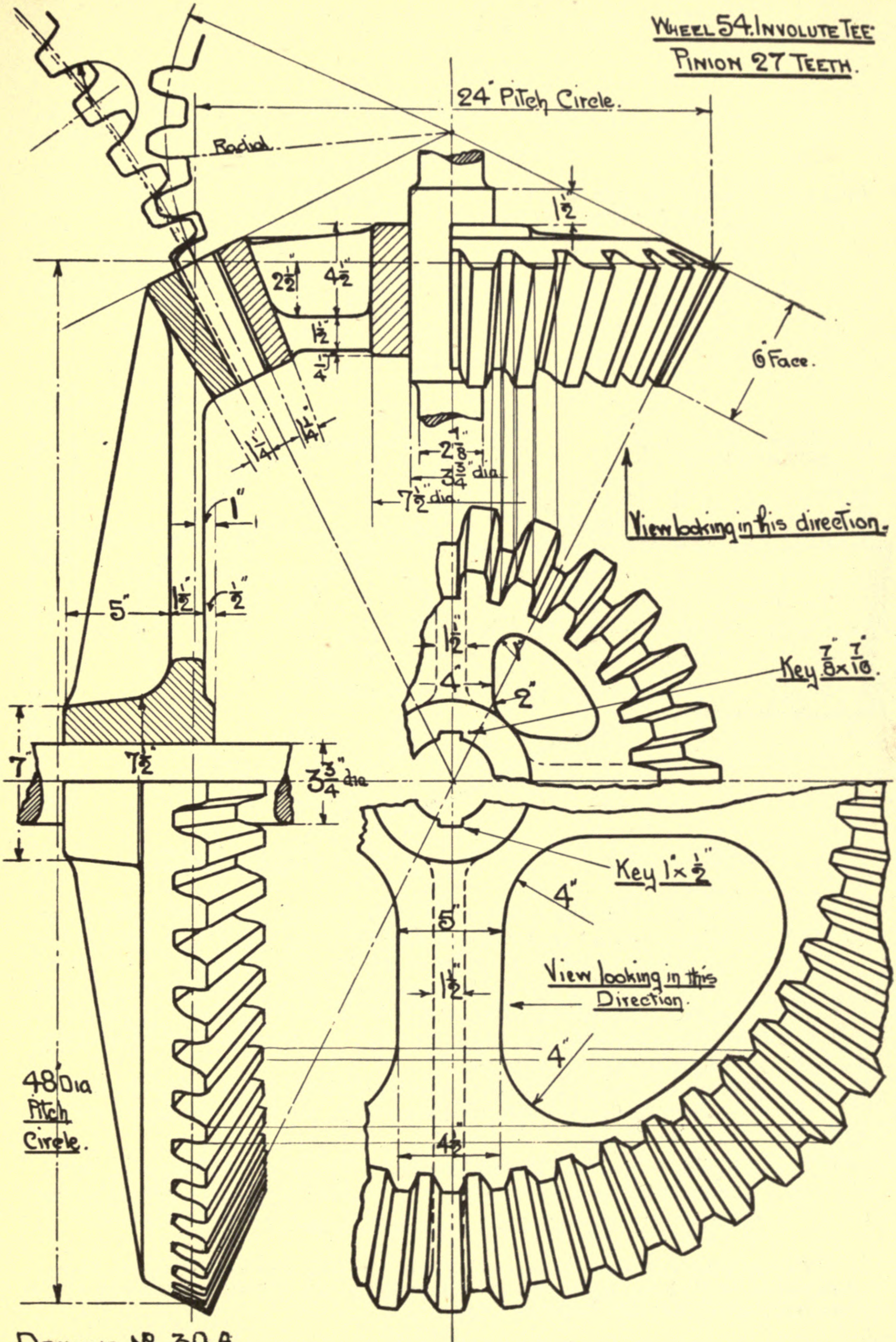
FIG. 114.—Teeth for Bevel Wheels.

line rolling on the development of these cones. The actual rubbing surface is formed by a straight line hinged at O, sliding over the contour so formed, the width of the tooth usually being 2·5 times the pitch. All dimensions are taken at the thick end of the tooth.

Draw to a scale of quarter full size the bevel wheels given, the velocity ratio being 2 to 1; involute teeth, large wheel 54 teeth, small wheel 27; pitch of teeth, 2·8 inches.

Examples—

1. What advantages are obtained by using helical teeth in spur and bevel gear?
2. Explain the process of machine moulding wheel gear.



Drawing No. 30.A.
Scale ¼ Full Size

Bevel Wheel and Pinion.

JOINT IN GIRDER WORK.

Drawing No. 31.[1]

Draw to a scale of quarter full size two elevations and a plan, to the particulars given in the top left-hand corner.

Examples—

1. Trace in ink, on tracing paper, the two views of the eye bar shown (fig. 115). Insert the dimensions and print the title as shown. The lines should be very black, of uniform and moderate width, and as continuous as possible.

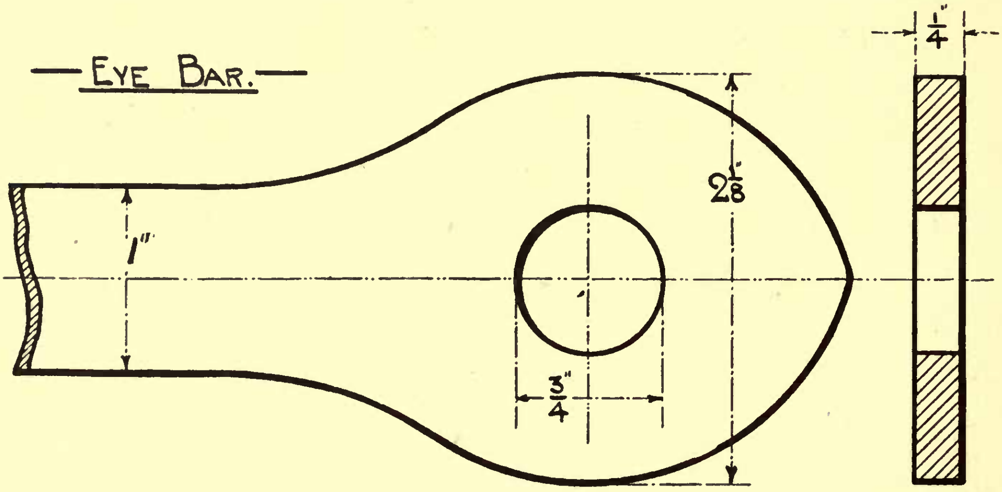


FIG. 115. ACTUAL SIZE.

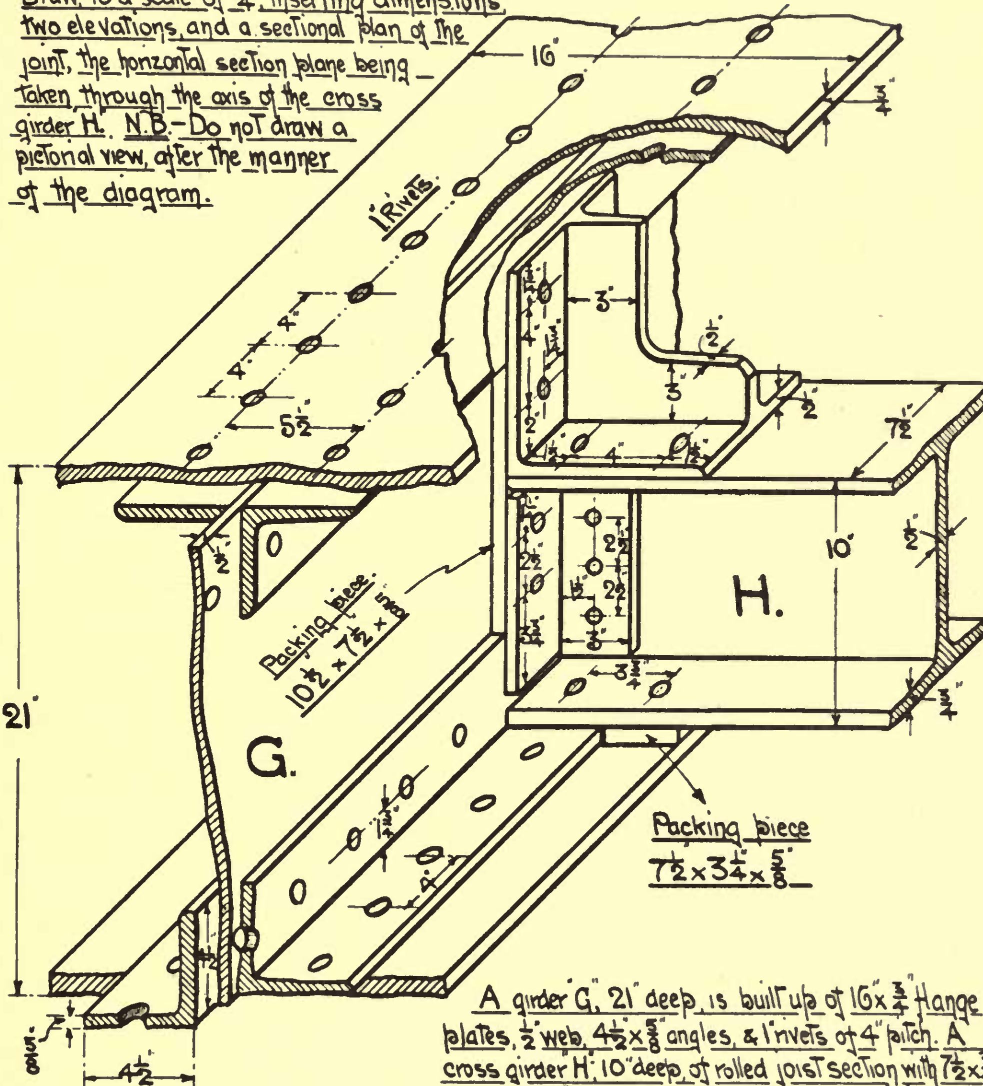
2. Sketch in longitudinal section, full size, a simple gland and stuffing box, suitable for a 1-inch piston rod, there being two $\frac{3}{8}$-inch gland studs, $2\frac{1}{4}$ inches apart from centre to centre, the diameter of the gland being $1\frac{5}{8}$ inches, and the internal depth of the stuffing box $1\frac{1}{2}$ inches. Insert dimensions. Describe how the packing is put in place.
3. Sketch in detail the insulator, and the method of fixing, for carrying an ordinary telegraph wire.
4. Sketch in section, half size, inserting dimensions, a flange joint for a 5-inch cast-iron steam-pipe secured by six $\frac{5}{8}$-inch bolts, dimensions as follows:—

Thickness of metal of pipe, $\frac{5}{8}$ inch.	Thickness of flange, $\frac{13}{16}$ inch.
Diameter of flange, 10 inches.	Radius of bolt circle, $4\frac{1}{8}$ inches.

State how the joint is made steam-tight.

[1] This drawing and examples are taken from the 1908 Board of Education, Stage I., Examination in Machine Construction and Drawing, and are printed by permission of the Comptroller of His Majesty's Stationery Office.

Draw, to a scale of $\frac{1}{4}$, inserting dimensions, two elevations, and a sectional plan of the joint, the horizontal section plane being taken through the axis of the cross girder H. N.B.—Do not draw a pictorial view, after the manner of the diagram.



A girder "G," 21" deep, is built up of 16" x $\frac{3}{4}$" flange plates, $\frac{1}{2}$" web, $4\frac{1}{2} \times \frac{5}{8}$ angles, & 1" rivets of 4" pitch. A cross girder "H," 10" deep, of rolled joist section with $7\frac{1}{2} \times \frac{3}{4}$ flanges, & $\frac{1}{2}$" web rests on the lower flange of G and is riveted to "G" by means of two $3\frac{1}{2} \times 3\frac{1}{2} \times \frac{1}{2}$ angle pieces each $7\frac{1}{2}$ long, and a bent $7\frac{1}{2} \times 3\frac{1}{2} \times \frac{1}{2}$ tee piece, as shown in the dimensioned pictorial sketch.

DRAWING No. 31.

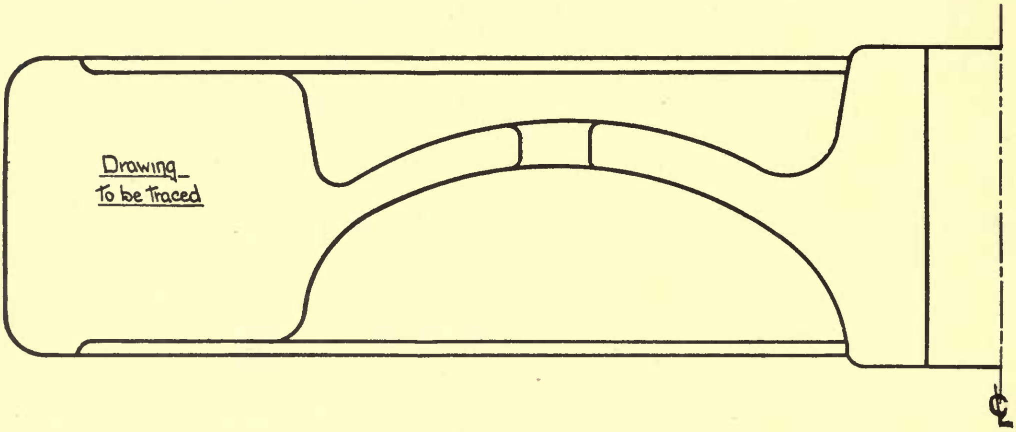
STEAM ENGINE GOVERNOR.

Drawing No. 32.[1]

Draw to a scale of three-quarters full size an outside elevation corresponding to the sectional elevation given, also a complete plan.

Examples—

1. Trace in ink, on tracing paper, the half fly-wheel pulley shown in fig. 116.
2. Sketch a flange joint suitable for connecting two 4 inches diameter steam-pipes carrying steam at a pressure of 120 lbs. per square inch.



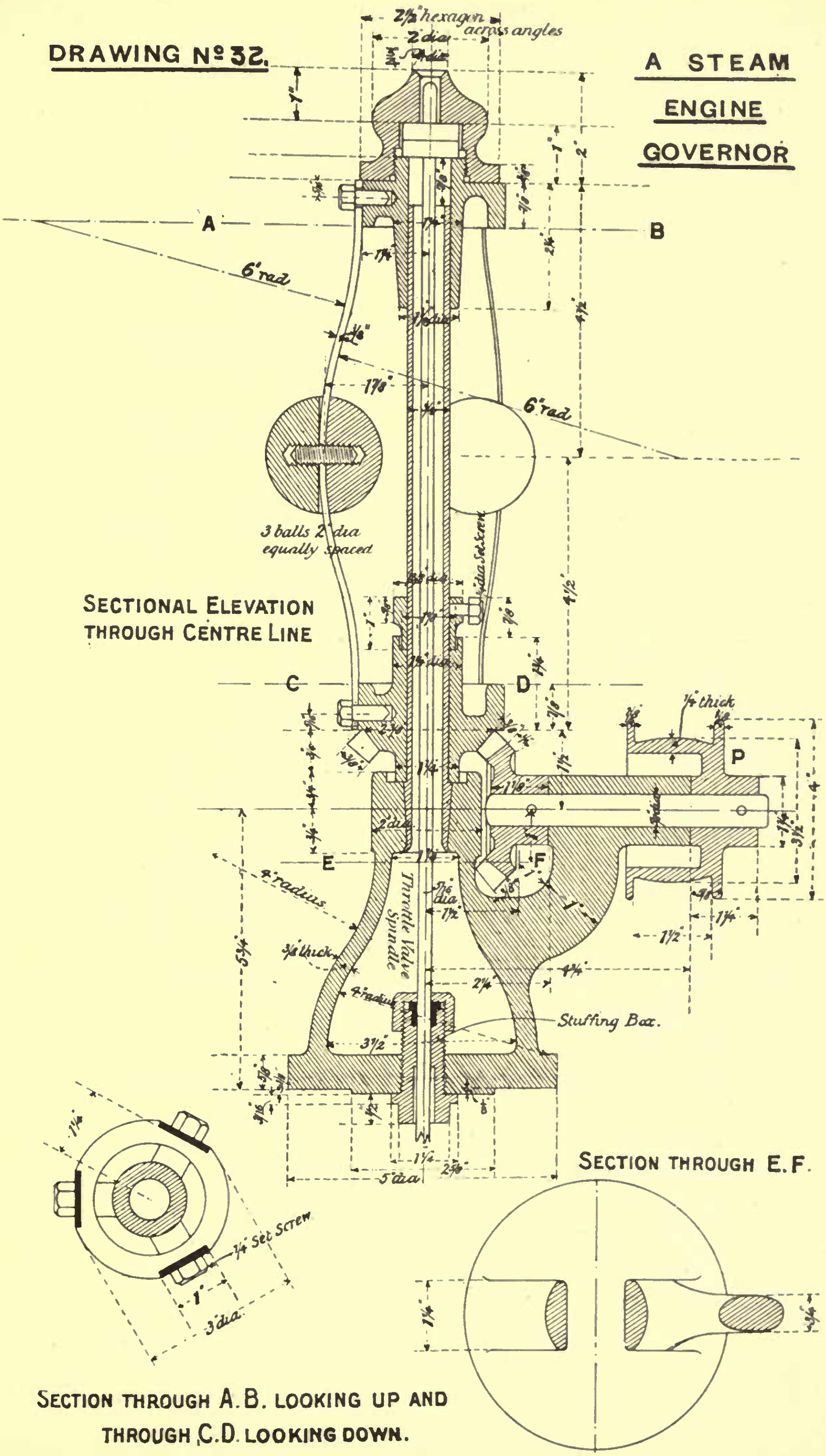
HALF SECTION OF A FLY WHEEL PULLEY. $\frac{5}{8}$s ACTUAL SIZE.

FIG. 116.

3. Make a sketch of a gusset stay suitable for staying the flat end of a Lancashire boiler.
4. Sketch a pattern suitable for the moulding of the pulley P for the governor, Drawing No. 32, and briefly describe how you intend that the pulley shall be moulded.
5. Make a sketch of an eccentric sheave, and show clearly how it is secured to the shaft.

   Sketch an end view of the shaft, and on it show the angular advance of the sheave and its radius or eccentricity, the crank being indicated by a dotted line, and the direction of rotation by an arrow. It is assumed that the eccentric is driving an ordinary slide valve.
6. Sketch a section of the armature of a small continuous-current motor, showing clearly the construction of the commutator and the armature core. You are not expected to show any of the windings, but only the mechanical details of the type of armature you select for description.

[1] This drawing and examples are taken from the 1908 Board of Education, Stage II., Examination in Machine Construction and Drawing.


DRAWING No 32.
A STEAM ENGINE GOVERNOR
SECTIONAL ELEVATION THROUGH CENTRE LINE
3 balls 2" dia equally spaced
Throttle Valve Spindle
Stuffing Box.
SECTION THROUGH E.F.
SECTION THROUGH A.B. LOOKING UP AND THROUGH C.D. LOOKING DOWN.

TOOL-HOLDER FOR A PLANING MACHINE.

Drawing No. 33.[1]

Draw the following views of the part of the planing machine tool-holder marked A to a scale of one-half full size:—

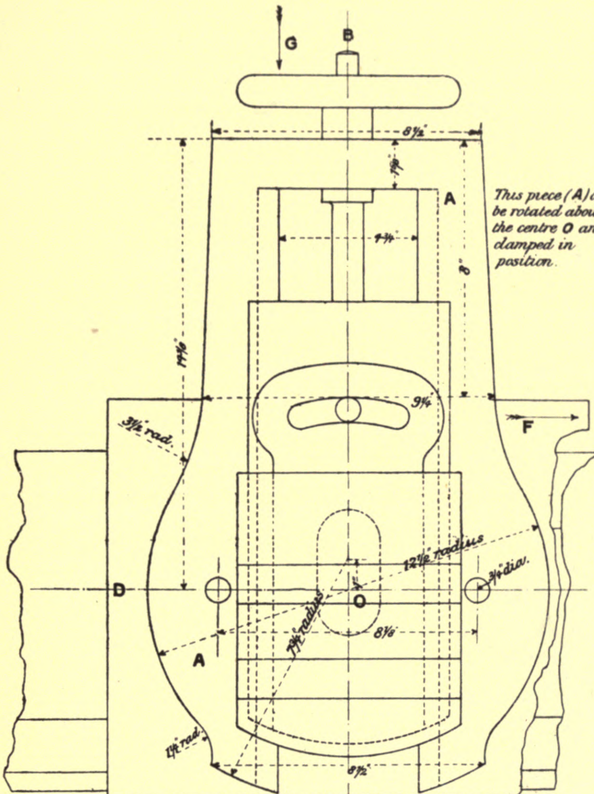
(*a*) A view of A corresponding to the outside elevation.
(*b*) A half plan and half section of A through the line DE, looking in the direction of the arrow G.
(*c*) A section of A through the centre line BC.

Note.—No other part of the holder is to be drawn but the part A. Neither dotted lines nor dimensions need be shown.

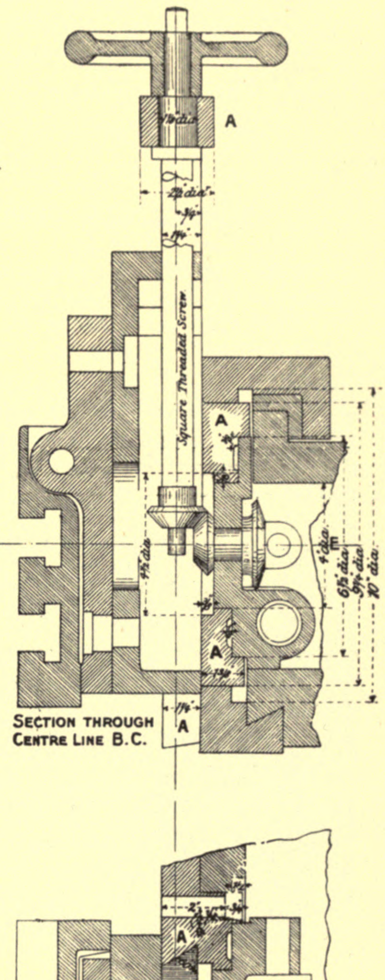
Questions—

1. Explain, with a sketch, how the tool is held by a tool post to the tool box when working. What construction in the tool box allows the tool to be relieved on the return stroke?
2. What is the cutting speed in feet per minute, when roughing and when finishing a cast-iron surface? Sketch the shape of the tools which would be used. Assuming them made from 1 inch square steel, indicate the angles to which they are ground.
3. Make a line diagram of a planing machine mechanism, showing how a quick return motion is obtained. What is the object of this, and what is the return speed relative to the cutting speed?

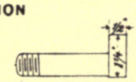
[1] This drawing is taken from Stage II., 1908, Board of Education Examination Paper.



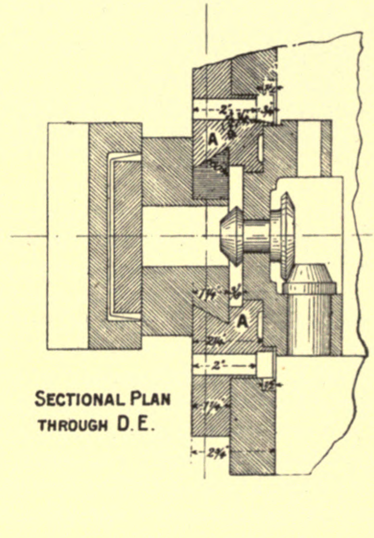
OUTSIDE ELEVATION
LOOKING IN THE DIRECTION
OF THE ARROW F.



SECTION THROUGH
CENTRE LINE B.C.



SQUARE HEADED
BOLT FOR
CLAMPING A.



SECTIONAL PLAN
THROUGH D.E.

DRAWING No. 33.

Tool-holder for a Planing Machine.

Do not draw the views as shown, but follow the instructions.

MATERIALS USED IN MECHANICAL ENGINEERING.

CONSIST mainly of cast-iron, wrought-iron, mild steel, steel castings, gun-metal and other bearing alloys, timber.

Cast-iron is obtained by smelting iron ores in the blast furnace. It is usually "run," that is, cast, into D-section bars about 3 feet long, and called pig-iron. It is a combination of iron with carbon and other substances, such as silicon, phosphorus, sulphur, and manganese. The carbon may be free or chemically combined, the greater the amount of free carbon, the darker being the fracture of the cast-iron; and the more carbon there is chemically combined,

FIG. 117.—Pattern, Core Box.

FIG. 118.—Core Box, Core Iron.

the harder the iron, and the whiter the fracture. Soft cast-iron contains about 0·2 per cent. of combined carbon, the usual run being 0·5 to 1 per cent. Chilling cast-iron prevents the carbon separating out, and a much harder iron is produced. Grey pig-iron melts at about 1200° C., and white pig-iron melts at about 2000° F. or 1100° C. Cast-iron at the moment of solidifying expands, taking a good impression of the mould, and then during cooling shrinks or contracts $\frac{1}{8}$ inch per foot, and this is allowed for in the dimensions of the pattern.

For ordinary machinery castings, pig-iron and scrap are remelted in the cupola and then run into sand moulds prepared from the patterns.

Figs. 117 to 120 illustrate the pattern, core box, with core irons and core partially made, core, mould, and finished casting.

The parts of a machine made from cast-iron are those forming the supports, that is, the stationary or static parts. Owing to its brittleness, it is not well adapted for use as a relative moving part, unless it is well supported.

The chemical composition of cast-iron may be taken as:—

	Light Iron Castings.	Soft Castings.	Grey Pig.	White Pig.
Combined carbon	0·4	0·46	·04	2·5
Graphitic carbon	3·1	2·75	3·1	·87
Silicon	2·5	3·0	2·5	1·2
Manganese	·4	1·2	·5	2·7
Phosphorus	·8	·8	·65	·75
Sulphur	·08	·03	·10	2·60

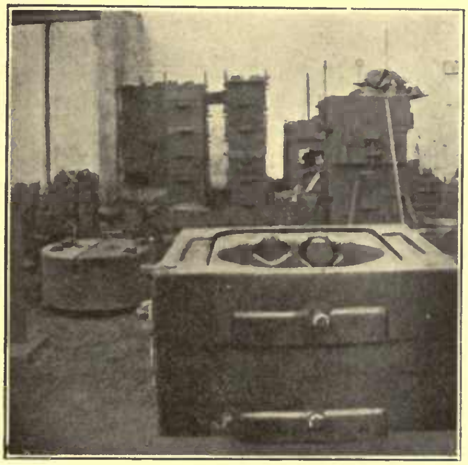


FIG. 119.—Mould (open).

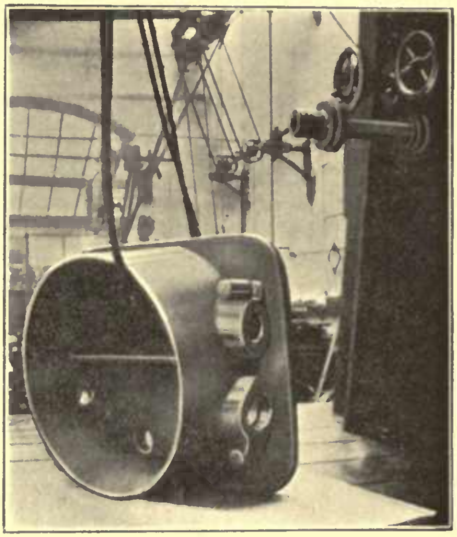


FIG. 120.—Finished Casting.

Wrought-iron is practically pure iron. Grey pig-iron is melted on the hearth of a reverberatory furnace, the bed of which contains oxide of iron and hammer scale. The impurities, silicon, manganese, and phosphorus, are oxidised and formed into slag, the carbon burning out. The metal becomes pasty, is taken from the furnace, hammered and rolled. It is tough and ductile, bending and stretching before it fractures, and is therefore useful for details subject to shocks and bending stresses. The melting-point of pure iron is about 1650° C. Before melting it becomes pasty, and can therefore be welded and forged into shape.

Malleable Cast-iron.—Iron castings can be given properties closely allied to those of wrought-iron by embedding the castings in powdered red hematite, an oxide of iron, and keeping them at a bright-red heat for a length of time

determined by the dimensions and shape of the casting. The process removes or separates some of the carbon in the cast-iron. It is used for details subject to rough usage which are of a shape difficult to forge from wrought-iron. To obtain successful malleable iron castings, the form and cross section of the detail must be carefully considered. The contraction which has to be allowed for in the pattern is $\frac{1}{10}$ to $\frac{3}{16}$ inch per foot.

Steel.—The difference between pig-iron, wrought-iron, and steel chiefly depends upon the relative amount of the carbon in chemical combination with the iron, and the method of production.

Comparative Chemical Composition, per Cent.

Material.	Carbon.	Silicon.	Manganese.	Phosphorus.	Sulphur.
Cast-iron . . .	3·25	2·5	·4	·8	·08
Wrought-iron . .	·075	·02	trace	·004	·03
Steel, soft . . .	·19	·05	·6	·045	·042
,, medium .	·30	·03	·55	·05	·03
,, hard . .	·75	·09	·50	·035	·04
Spiegeleisen . .	5·0	·4	7·6	·16	·08

Steel is a compound of pure iron and carbon, the percentage of carbon varying up to 1·8; when it is low, or under 0·25 per cent., the metal is termed **mild steel** or ingot iron. The melting-point varies with the amount of carbon from 1300° to 1800° C. Steel containing upwards of 0·5 per cent. of carbon has the property of hardening after being heated to redness, and plunged while still hot into mercury, water, or oil, and can then be tempered by reheating to a temperature lower than that used in the hardening process, and quenching.

Table of Temperatures—Centigrade Degrees.

400	Light is just observed.
525	Dark red heat.
900	Cherry red.
1000	Clear cherry red.
1200	Clear orange.
1300	White heat.
1500	Dazzling white heat.
2000	Temperature of electric arc.

Mild Steel is obtained by the *Bessemer* process, in which a powerful blast of atmospheric air is forced through molten pig-iron, in a vessel mounted on trunnions called a converter. The impurities in the iron are oxidised, forming slag, and the carbon is burnt out, the iron being decarburised. A small percentage of carbon is then given to the iron by the addition of spiegeleisen or ferromanganese, the manganese removing the excess of oxygen in the molten metal, which is then cast into ingot moulds, and worked into bars and plates as required. It is also obtained by the *open-hearth* process, in which fusion of pig and scrap iron takes place on the hearth of a furnace in the presence of or with certain classes of ore, the bath of molten metal being first decarburised and then recarburised by the addition of ferromanganese containing manganese 85 per cent., iron 10 per cent., carbon 3 per cent., silicon 2 per cent.

Tool Steel is produced by the cementation process, that is, the carburisation of wrought-iron. Bars 3 inches × $\frac{1}{2}$ inch of Swedish iron are embedded in wood charcoal, and heated up to a temperature of 1170° C., which is maintained for eight or nine days, the bars obtained being called blister steel. They are cut up and worked into bars as required.

Crucible Cast Steel.—The blister steel obtained is made perfectly homogeneous by breaking up and grading, then melting in crucible 6 inches diameter, 18 inches high, casting into ingots, and drawing down into bars.

Gun-metal is an alloy of copper, tin, and zinc or spelter, lead being added to toughen it, assist in machining, and reduce cost. The composition varies widely. The alloy containing 78 copper, 10 tin, and 12 zinc may be taken as typical. The physical properties depend upon the composition, mode of manufacture, mechanical treatment, and rate of cooling after heating. The melting-point is 600° to 750° C., and the contraction to be allowed for in the pattern is $\frac{3}{16}$ inch per foot.

Hard Solders are alloys of copper and zinc used for jointing pieces of metal together (brazing). They must have a lower melting-point than the bodies being united, but the nearer to it the better the joint. Borax is generally used as the flux.

Soft Solders are alloys of lead and tin, varying from 1 tin, 10 lead, to 5 tin, 1 lead, the quality being judged by the appearance of the fracture.

Table of Melting-points of Metals, in Centigrade Degrees.

Platinum	1780	Aluminium	625
Iron	1600	Zinc	415
Grey pig-iron	1250	Lead	326
White pig-iron	1150	Tin	230
Copper	1050	Mercury	−39

Weight of Castings.—It is often necessary to know the probable weight of a casting before it is actually cast—first, for estimating purposes; second, to arrange for a sufficient quantity of metal in the casting ladle before pouring. The first is obtained from the drawing by working out the volume, and knowing the weight of unit volume of the metal. The casting is always heavier than the weight so estimated, to which, therefore, about 5 per cent. is usually added. To obtain the weight for the second purpose, the pattern will be in existence, and by weighing it, and using a table similar to the one below, the weight is obtained.

Weight of Castings by Weighing Pattern.

1 lb. of pattern made of	will give a casting lbs. when cast in—		
	Cast-iron.	Gun-metal.	Yellow Brass.
Spanish mahogany	8·5	9·9	9·7
Red pine	12·5	14·6	14·2
White pine	16·7	19·5	19
Yellow pine	14·1	16·5	16
Oak	9	10·9	10·1

Comparative Weight of Materials.

Material.	Lbs. per cubic foot.	Lbs. per cubic inch.	Material.	Lbs. per cubic foot.
Water	62·32	·03616	Spanish mahogany .	55
Sea-water . . .	64·0	·037	Teak	49
Soft cast-iron . .	443·4		Oak	47
Medium cast-iron . .	447·4	·26	Red pine . . .	40
Hard cast-iron . .	454·2		Yellow pine . . .	33
Wrought-iron . .	485	·28	Green timber $\frac{1}{8}$ to $\frac{1}{2}$ more	than dry.
Soft steel . . .	490·8		Loose earth . . .	76
Medium steel . .	490·4	·284	Cement	90
Hard steel . . .	490		Ordinary brick . .	112
Gun-metal . . .	536	·31	Clay	120
Brass	525	·3	Wet sand . . .	130
Copper	550	·32	Pressed brick . .	140
Tin	455	·263	Stone	150
Lead	711	·41		
Zinc	437	·253		
Mercury . . .	849	·49		
Platinum . . .	1342	·78		

Density and Volume of Water.—The weight of 1 cubic foot of water in the above table is when at its maximum density. The way in which unit volume varies as the temperature varies is shown by the following table:—

Temperature. Degrees Centigrade.	Volume.
0	1·000127
4	1·
10	1·000269
20	1·001768
30	1·004345
100	1·04312

One gallon of water equals 10 lbs. at a temperature of 62° F.
A column of water 1 foot high equals a pressure of ·434 lb. per square inch.
A pressure of 1 lb. per square inch equals a column of water 2·31 feet high.
One cubic foot of air at 0° C. and one atmosphere pressure weighs 0·0807 lb.

Corrugated Iron Sheets—Weight per Square Yard.

Thickness, B.W.G. .	16	18	20	22	24	26
Weight in lbs. . . .	32	24	19	16	13	11
Add about $\frac{1}{8}$ of the weight for lapping.						

Questions—

1. What is the weight in lbs. of 1 cubic foot of water at a temperature of 100° C.?
2. Take the specific gravity of water as 1, and make a table showing the specific gravity of the metals relative to water.

$$\text{Specific gravity} = \frac{\text{weight of unit volume of metal}}{\text{weight of equal volume of water}}.$$

On the metric system the weight of a given volume is readily obtained by taking the volume in cubic centimetres, multiplying by the specific gravity, obtaining the weight in grammes.

3. Test different metals on a dry emery wheel, and note the character of the sparks thrown off.
4. Say in a general way how the presence of silicon, phosphorus, sulphur, and manganese affects the properties and characteristics of cast-iron.
5. Describe briefly the appearance of the fracture of the different metals (1) when steadily drawn out, (2) when twisted off, (3) when broken by an impact, that is, with a shock.
6. Describe the process of case-hardening small finished wrought-iron details.
7. What is the tempering colour given to wood saws, cold chisels, twist drills, punches and dies, taps and hammer faces? Roughly, what temperature does each of the colours correspond to?
8. What is the composition of Muntz metal? What are its properties, and under what circumstances is it most desirable to use it?
9. What is the object of a flux when soldering? What flux is usually employed for common or soft solder?
10. In the table of melting-points of metals, convert the Centigrade temperatures into Fahrenheit readings, making a table showing the comparison.

Strength of Materials.

In deciding of what material a detail should be made, the first consideration is that of ease with which the material can be obtained in the desired shape, its dimensions being then fixed by a knowledge of the properties of the different materials, relative values concerning which are obtained by considering the behaviour of a sample tested to destruction.

A structure is usually called upon to resist forces producing tension, compression, torsion, bending, and shearing in the material of which it is made; and it may rupture or fracture, due to strains produced by each or any of the different types of loading.

Tension Tests.—The value of a material to resist a load tending to lengthen it is decided by taking a sample piece and turning it to a form shown in fig. 121. The ends being screwed into ball and socket clips of the testing

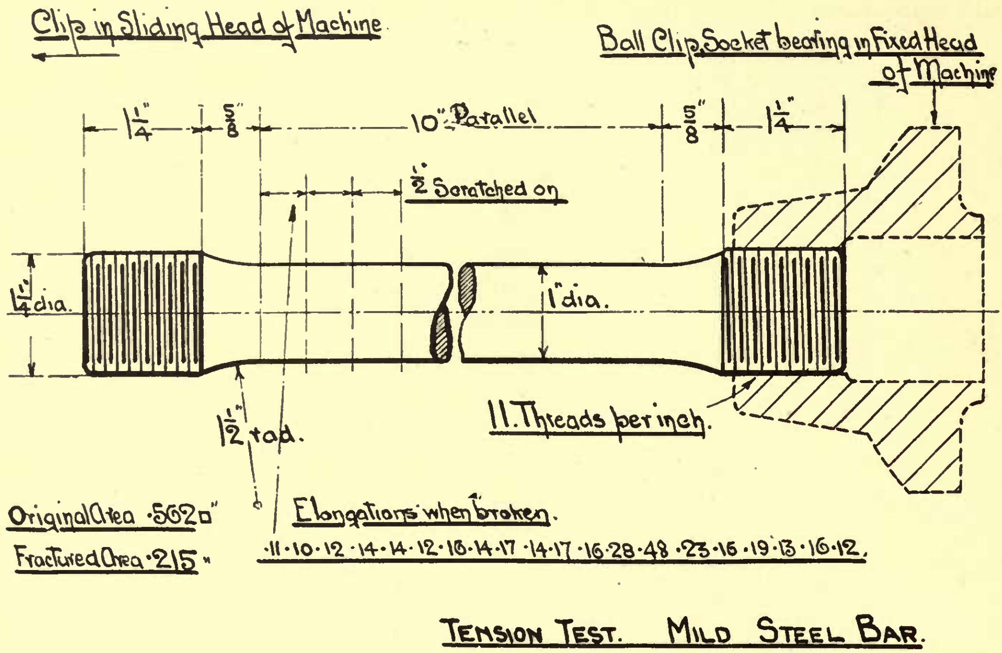


Fig. 121.

machine, a gradually increasing load is applied at a definite rate, and the behaviour of the bar noted.

Example.—A bar of mild steel containing 0·26 per cent. carbon, taken in the direction of the grain from a billet made from Scotch hematite iron in an acid open-hearth Siemens furnace, using Spanish hematite ore for reducing

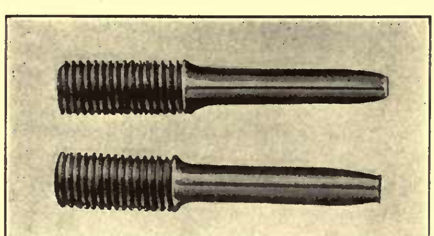


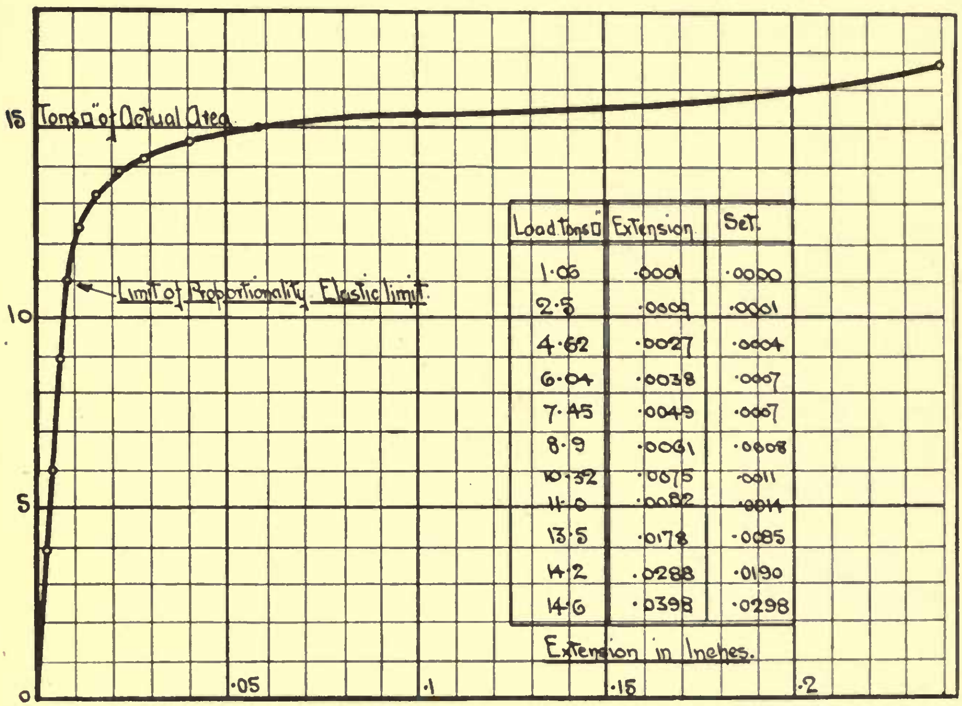
Fig. 122.—Tension Test Bar, broken.

it, was turned to the dimensions given in fig. 121, and the load then applied at the rate of 0·1 ton per minute.

(*a*) Up to a certain point, called the *elastic limit*, the stretch is proportional to the load (see fig. 123) (below this limit, if the load be removed, the bar immediately goes back almost to, and in time exactly to, its original length).

(*b*) The stretch then increases at a faster rate, until in the case of ductile metals only the bar suddenly gives way at a load called the *yield-point*. This is confined to rolled materials, and is not noticed in a bar cut from a casting.

(*c*) A ductile bar then assumes a plastic state, and stretches rapidly as the load is applied, the stretch being uniform along its length until maximum load is reached, when local necking in takes place, the sectional area diminishing and fracture taking place (fig. 122).



Load Tons □"	Extension	Set.
1·05	·0004	·0000
2·5	·0009	·0001
4·62	·0027	·0004
6·04	·0038	·0007
7·45	·0049	·0007
8·9	·0061	·0008
10·32	·0075	·0011
11·0	·0082	·0014
13·5	·0178	·0085
14·2	·0288	·0190
14·6	·0398	·0298

FIG. 123.

The complete test, with all the definite information required, is shown in fig. 124. The various points so clearly shown on it are not so well defined in the case of the more brittle materials.

Example.—From the data obtained calculate the *modulus of elasticity*, **E**—the load which, provided the bar remained perfectly elastic, would stretch it to twice its original length.

$$\text{Stress} = \frac{\text{load in lbs.}}{\text{area in square inches}} = 6{\cdot}4 \times 2240 \text{ lbs. per square inch.}$$

$$\text{Strain} = \frac{\text{extension within the elastic limit}}{\text{length on which the extension is measured}} = \frac{{\cdot}0052}{10}.$$

$$\begin{aligned} E &= \text{stress} \div \text{strain} \\ &= \frac{6{\cdot}4 \times 2240}{{\cdot}00052} \\ &= 27{,}570{,}000 \text{ lbs. per square inch.} \end{aligned}$$

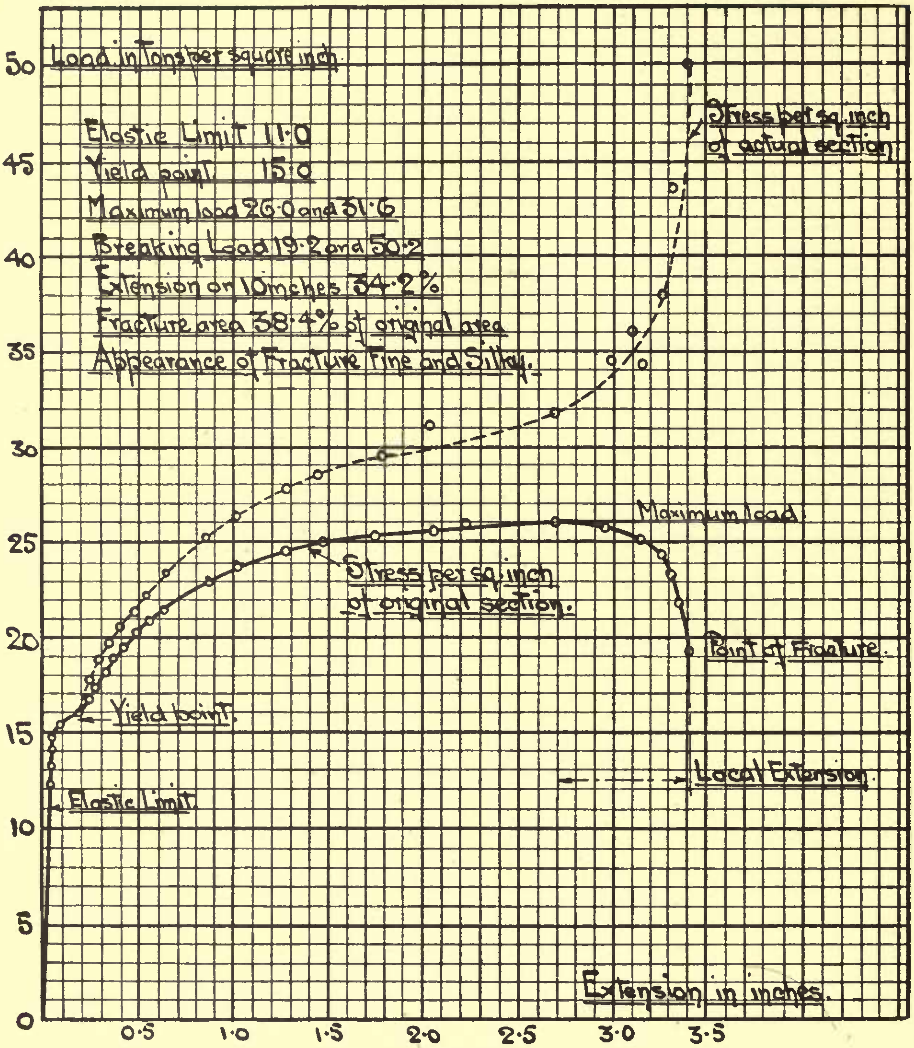


Fig. 124.

Example.—Describe a tension test on a bar of cast-iron, explaining the behaviour and the definite information which would be obtained.

Torsion Tests.—To obtain a knowledge of the properties of a material when carrying loads producing a twist in it, a sample is cut to the form shown in Drawing No. 2, Card No. 1. One end is rigidly held and the other twisted round, the behaviour of a definite length in the body part of the bar being particularly noted.

Example.—A bar of the same material as used for the tension test example—diameter, 1·008 inches; shape, Card No. 1, Drawing No. 2—was fixed in the machine, and by means of a hand wheel, worm, and worm wheel, one end

twisted relative to the other, by the application of a twisting moment at the rate of 60 inch-lbs. per minute, a weighing machine arrangement enabling

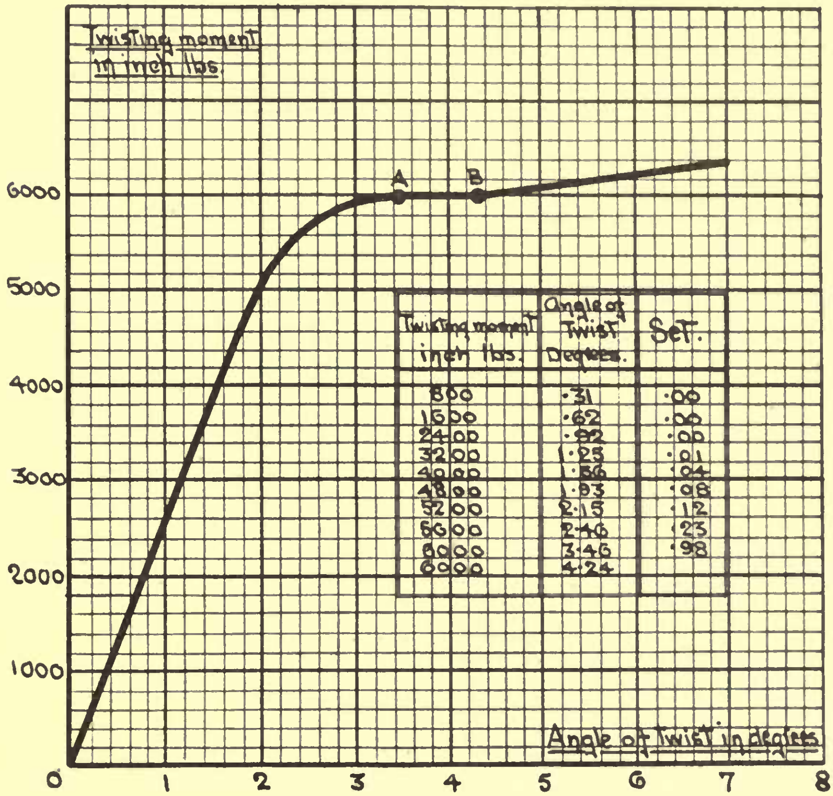


FIG. 125.

the twisting moment to be recorded. The relative motion of two sections 8 inches apart on the body of the bar was measured in degrees.

(*a*) Up to 4000 inch-lbs. the angular movement is proportional to the twisting moment. At this point, if the load be left on the bar, a creeping action takes place, the bar giving way with time, finally becoming steady, *i.e.* we have reached the limit of proportionality or the *elastic limit.*

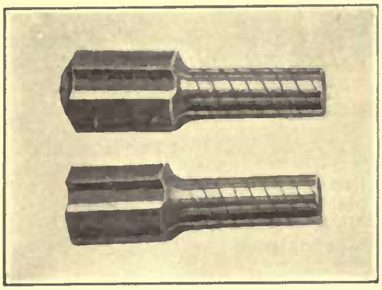


FIG. 126.—Torsion Test Bar, broken.

(*b*) After this point, with the same rate of loading, the bar gives way, that is, twists at a faster rate, until with a moment of 6000 inch-lbs. it suddenly gives way

—the *yield*-point is reached. To show how the bar would continue to twist at a constant load, the twisting moment was maintained at 6000 inch-lbs., under which the bar twisted through an angle of 0·78 degree in 26 minutes, as shown from A to B in the curve, fig. 125. Afterwards the rate of loading was continued until finally the bar twisted off on a section practically perpendicular to the axis of the bar (see fig. 126).

Modulus of Rigidity, **N**, is the constant expressing the relation which exists between the moment and the twist which it produces, within the elastic limit, and

$$N = \frac{\text{twisting moment} \times \text{length}}{\text{twist} \times \text{moment of inertia}}.$$

Example.—From 1000 to 4000 inch-lbs. the twist on 8 inches is $(1·56 - ·38)$ degrees.

$$N = \frac{M \, . \, l}{\theta \, . \, I}.$$

$M = 3000$ inch-lbs. $l = 8$ inches.
$\theta = 1·18$ degrees $= 1·18 \times \pi \div 180$ radians.
$I = \pi \, . \, r^4 \div 2$ for a round bar polar axis.

$$\therefore \quad N = \frac{3000 \times 8 \times 180 \times 2}{1·18 \times \pi \times \pi \times ·504^4} = 11{,}500{,}000 \text{ lbs. per square inch.}$$

Example.—Up to the elastic limit, the maximum stress in the material, which is at the outer surface, is for a round bar given by the formula

$$T.M. = \frac{\pi}{16} . f . d^3.$$

Taking T.M. corresponding to the elastic limit as 4000 inch-lbs., what is the maximum stress, expressed in tons per square inch ?

Questions—

1. Describe a torsion test on a bar of cast-iron, taking the bar through the various stages from no load to fracture.
2. What is the ratio of E to N, taking the foregoing values for mild steel.

The datum most easily obtained when testing materials is the maximum load carried per square inch of original area, and this is called the **ultimate strength**.

Ultimate Strength of Materials—Tons per Square Inch of Original Area.

Material.	Tension.	Compression.	Shear.	E in lbs. per square inch.	Remarks.
Cast-iron . . .	9	44	7	20,000,000	
Malleable-iron castings .	14	...	...	...	Elongation 2 per cent. on 4 inches.
Wrought-iron . .	22	21	20	27,000,000	Elongation 15 per cent. on 8 inches. Reduction of area 20 per cent.
Mild steel . . .	30	32	26	30,000,000	Elongation 20 per cent. on 8 inches. Reduction of area 40 per cent.

Ultimate Strength of Materials—Tons per Square Inch of Original Area.—contd.

Material.	Tension.	Compression.	Shear.	E in lbs. per square inch.	Remarks.
Steel castings	31	...	...	...	Elongation 34 per cent. on 2 inches. Reduction of area 52 per cent.
Copper	18	20	11	15,000,000	Elongation 15 per cent. on 8 inches
Phosphor bronze	26	...	19	13,000,000	
Gun-metal	15	14	14	11,500,000	
Brass	8	4·75	...	9,000,000	Elongation 10 per cent. on 8 inches. Reduction of area 10 per cent.
Baywood	6	...	...	1,500,000	
Red pine	4·5	2·5	·3 and 1	1,750,000	With and across grain.
Red brick	·15	·5	...	...	

As the real behaviour of a material in a structure should be determined by its properties up to the elastic limit, for comparison a table is added showing the stress in tons per square inch of area, corresponding to the elastic limit of the most common materials.

Elastic Limit of Materials.

Material.	Tension.	Compression.	Shear.	Remarks.
Cast-iron	4·75	9·5	3·5	Test not to exceed 3·5 tons per square inch.
Malleable-iron castings	9·0	...	...	
Wrought-iron	9·0	9·0	6·75	
Mild steel	11·0	11·0	9·0	
Steel castings	15·5	...	...	Test not to exceed 11 tons.
Copper	2·0	1·75	1·25	
Phosphor bronze	9·0	...	6·5	
Brass	3·0	...	2·5	

Working Strength of Materials.—By the process of trial and error, practical men have decided upon what proportion the working load should be of the ultimate strength, when the structure may be called upon to carry a load or loads of the different types.

Factor of Safety.—The general idea of the quality of a material is obtained from the data given by testing the material to destruction, and comparative values so obtained enable the relative advantages to be discussed and decided upon. It will, however, have been noted that, say in the case of mild steel subject to tension, a definite rupture-point occurs long before the material breaks. Obviously, should the mild steel in practice be strained to this rupture-point, deformation of the structure will take place, and the construction will be said to have failed. Before the definite yield-point is reached, which in the case of the more elastic materials, glass, hard steel, cast-iron, is not well defined, a point, the elastic limit, is reached, beyond which, if the material is strained,

it will not return to its original dimensions. Hence, under any conditions likely to be met with during working, the material must not be strained beyond this elastic limit. For mild steel this is 11 tons per square inch.

In practice it would be unwise to run the load on mild steel so high. Precautions must be taken and allowances made for damage and loss which would be caused by failure, defective material and design, the effects of shock, wear, corrosion, and temperature.

Thus, in the most favourable case the load on mild steel may be 5 tons per square inch, and it is then said the factor of safety is 6.

$$\text{Factor of safety} = \frac{\text{working load per square inch of area}}{\text{ultimate strength per square inch of area}}.$$

A general idea of what this ratio is taken to be for the different loads coming on a structure is given by the table, but on top of these values the other considerations must be allowed for :—

Factors of Safety.

Material.	Steady Load.	Live Load in one Direction.	Alternating Live Load.	Shocks.
Cast-iron	4	6	8	15
Wrought-iron and mild steel . .	3	5	10	12
Timber	7	10	15	20
Masonry	20	30	...	...

When fixing the number to be used as the factor of safety, the character of the load carried by the structure is carefully considered. The following table shows roughly what may be taken as the working load for the most common materials.

Working Stress in Tons per Square Inch.

Material.	Constant Load.	Variable Load in one Direction.	Variable Load, Changing Direction.	Remarks.
Cast-iron . . .	1·5	·75	·375	In tension.
	7	4·5	·375	In compression.
Wrought-iron . .	6	3	1·5	In tension.
	5	2·5	1·5	In compression.
Mild steel . . .	8	5	2·5	In tension.
	10	7·5	2·5	In compression.
Gun-metal . . .	1·25	...	...	In tension.
	1·25	...	...	In compression.

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